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AIRCRAFT ENGINE SUMP FIRE MITIGATION

by

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SKF INDUSTRIES, INCORPORATED

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68

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16. Abstract

An investigation was performed of the conditions in which fires can result and be controlled within the bearing sump simulating that of a gas turbine engine; Esso 4040 Turbo Oil (MIL-L-7808 type ester), Mobil Jet II (MIL-L-23699 type ester), and Monsanto MCS-2931 (modified C-ether) lubricants were used. Control variables include the oil inlet temperature, bearing temperature, oil inlet and scavenge rates, hot air inlet temperature and flow rate, and internal sump baffling. In addition to attempting spontaneous combustion, an electric spark and a rub (friction) mechanism were employed to ignite fires.

Spontaneous combustion was not obtained; however, fires were readily ignited with the electric spark while using each of the three test lubricants. Fires were also ignited using the rub mechanism with the only test lubricant evaluated, Esso 4040. Major parameters controlling ignitions were: sump configuration; bearing and oil temperatures, hot air temperature and flow and bearing speed.

Rubbing between stationary parts and rotating parts (eg. labyrinth seal and mating rub strip) is a very potent fire source suggesting that observed accidental fires in gas turbine sumps may well arise from this cause.

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66

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FOREWORD

The research described herein, conducted by the SKF Industries, Inc. Research Laboratory, was performed under NASA Contract NAS3-14310. The work was completed under the management of the NASA Project Manager, Mr. William R. Loomis, Fluid Systems Components Division, NASA Lewis Research Center.

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TABLE OF CONTENTS

LIST OF ENCLOSURES

SUMMARY

The object of the research performed under this contract was to explore design and material concepts that can minimize the incidence of lubricant sump fires in high speed aircraft turbine engines. Engine sump fires have been experienced that may have resulted from a number of different causes. Therefore, there has been a need for work to lessen the chance for sump fires, control them once they have started by any means, or try to eliminate their possibility in the first place.

A test rig designed and built by SKF for the purpose of testing aircraft gas turbine mainshaft thrust bearings (125 mm bore) at high temperatures and speeds was modified to accommodate sump fire testing and operated within a system of drive, controls and mass flow sources. The modifications included; the incorporation of two fire ignition devices - a spark generator and a rub (friction) mechanism; the relocation of the high pressure oil seal in the low pressure air seal position; the addition of a seal lift-off mechanism; a separate oil system each for the test and rig bearing and the necessary new instrumentation and control components.

The test fluids evaluated for fire retarding properties and used for lubricating the thrust (test) bearing were Esso 4040 Turbo Oil (a MIL-L-7808 ester), Mobil Jet II (a MIL-L-23699 ester), and Monsanto MCS 2931 (a modified C-ether). Non-flammable Krytox 143-AC (perfluorinated organic polymer) fluid was used throughout the program to lubricate the rig bearing for safety considerations.

Testing was initiated with Mobil Jet II lubricant in attempts to obtain spontaneous combustion. These tests were executed by first obtaining the desired test conditions (bearing outer ring temperature of 550 to 600° F, inlet oil temperature between 380 and 400° F, and hot air temperature between 800 and 1100° F) in the test bearing chamber and then opening the seal to permit a high flow of hot air to enter the bearing chamber. After several tests, it became apparent that this technique does not produce spontaneous combustion in the test rig. An electric spark generator was then incorporated into the bearing chamber and a more flammable lubricant, Esso 4040 placed in circulation to aid in the ignition of fires. This approach was pursued since fires inadverently started in test rigs on previous programs at SKF were

triggered by an outside energy source, i.e. rubbing parts in the chamber. It was felt at the time that a spark generator was an acceptable simulated energy source and was easier to control than a rub device.

Baseline testing was performed with all three lubricants using the spark generator as an ignitor. Fires were readily ignited with all three lubricants when a given severity of test conditions (temperatures, speed, hot air flow) was reached. These tests were performed by increasing the severity of test conditions, particularly the hot air temperature, until a fire could be ignited. Seal leakage during these tests was sufficiently high to make it unnecessary to open the seal and the hot air flow rate was controlled by changing the pressure in the hot air chamber.

Additional tests were performed to evaluate the fire retarding properties of Freon 113 (a liquid) and FE1301 (a gas at room temperature). These tests were performed in the same manner as the baseline tests with the exception that the retardant was mixed with the lubricant by injecting it into the supply pipe approximately one foot prior to its entering the test rig. Freon 113 was evaluated with Esso 4040 lubricant in quantities of 1 and 5 percent by volume of the lubricant which was circulated at a rate of 1.2 gpm. Freon FE1301 was evaluated with both Mobil Jet II and Monsanto MCS 2931 in quantities as high as 10 percent. Both Freons were helpful in preventing ignition and retarding fire propagation. However, the primary retarding mechanism was judged to be cooling of the lubricant and not chemical in nature.

One test series was performed using a rub ignitor as an ignition source with Esso 4040 lubricant. The ignitor was a metal rub shoe pressed with known load against a rotating ring on the shaft. In all three runs, fires were readily ignited within approximately 5 seconds after the rub mechanism was actuated.

The principal conclusions reached as the result of the project are:

1. The principal operative parameters influencing fires in bearing chambers of gas turbines, identified in this

program are: chamber design; hot air inflow rate and temperature; operating speed, oil flow and temperature and bearing temperature. Lubricant type (varied spontaneous ignition temperatures) has a moderate effect. Fire retardant additives are moderately helpful. The severity of conditions needed to ignite and sustain a fire depends on the source of ignition. An external energy source, a spark or the heat from high speed sliding, is needed to ignite a fire under all conditions tested but once ignited, many fires are self-sustaining.

INTRODUCTION

A recognized need exists in the aircraft gas turbine industry for establishing causes and conditions under which fires are ignited in the mainshaft bearing chambers and how these fires can be prevented or quickly extinguished. The need results from accidental fires occasionally occurring in these areas in flight and the resulting danger to personnel and damage to equipment. It is the opinion of many knowledgeable sources that such fires occur spontaneously in an engine bearing compartment as the result of hot compressor air or combustion products entering through a faulty seal and/or the development of localized hot spots on the bearing cavity vent lines.

Lubrication sump fires have been encountered in high temperature operation of advanced engine components. These fires have occurred during flight experience, engine ground tests, and advanced laboratory evaluations of lubrication systems (NASA Contract NAS3-6267 at SKF (1)*) and mainshaft seal studies (NASA Contract NAS3-7609 at Pratt & Whitney (2)). The fires have resulted from a number of different causes that point to the need for experimental work to lessen the chance for engine sump fires, control them once they start by any means, or try to eliminate their possibility in the first place. Means of sump fire mitigation are a real requirement now and will become more stringent with anticipated increased severity of engine operating conditions.

The material presented in this report can be useful to the engine designer when evaluating the severity of environmental conditions within the bearing sump relative to conditions which will result in fire ignition and propagation, and in employing fire retardant and extinguishing methods to minimize fire damage.

The purpose of the work performed was to experimentally explore design and material concepts that can minimize the incidence of lubricant sump fires in high speed aircraft turbine engines. The work was performed in a simulated gas turbine mainshaft test rig and was divided into three tasks. Briefly these tasks consisted of the following.

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*Numbers in parentheses designate References.

Task I - Modification of a simulated gas turbine mainshaft test rig to operate as a test device to study lubricant sump fire mitigation.

Task II - Perform a series of baseline tests to establish bearing chamber environmental conditions which can produce spontaneous combustion. Should spontaneous combustion not occur, establish conditions using Esso 4040 lubricant under which fire can be ignited with an electrical spark. Determine the retardant effect of Freon 113 when introduced into the chamber with the lubricant.

Task III - Additional baseline tests with Mobil Jet II and Monsanto MCS 2931 lubricant using the spark ignitor. Establish the retarding effect of Freon FE1301 when employed with Mobil Jet II and Monsanto MCS 2931. Design, construct and perform tests using a rub (friction) device as a potential source of ignition to render the testing more realistic and applicable.

TEST MATERIALS

Three test lubricants 1) Esso 4040 Turbo Oil 2) Mobil Jet II 3) Monsanto MCS 2931, and two fire retardant compounds 1) Freon 113 2) Freon FE1301 were employed during the testing program.

Esso 4040 Turbo Oil is a dibasic acid ester of monohydric alcohol formulated with proprietary additives and meets MIL-L-7808 specifications. It has a flash point of 450°F, a fire point of 500°F, and a Spontaneous Ignition Temperature (S.I.T.) of 685°F.

Mobil Jet II is an ester-base formulation meeting the MIL-L-23699 specification. This oil is a second generation of an oil type previously supplied to MIL-L-7808 specifications. In its present formulation more stable base stock components have been used which were not previously available. It has a flash point of 485°F, a fire point of 545°F, and an S.I.T. of 810°F.

Monsanto MCS 2931 is a formulated C-ether (modified polyphenyl ether). It does not have a high molecular weight or viscosity as some of the other polyphenyl ethers and seems to be a stable lubricant under a wide range of ambient conditions. It has a flash point of 480°F, a fire point of 540°F, and an S.I.T. of 940°F.

In general Freons are organic compounds combining one or more carbon atoms and halogen atoms. Their principal characteristics include non-flammability, low toxicity, excellent thermal and chemical stability, high density coupled with low boiling point and low viscosity and surface tension.

Freon 113 ($CCl_2F-CClF_2$) has a molecular weight of 259.9 and a boiling point of 117°F. It is used primarily as a refrigerant in air conditioners but exhibits fire extinguishing properties as do most Freons (3). However, it is a questionable fire mitigating agent since it generates highly toxic gas when burned.

Freon FE1301 ($CBrF_3$) has a molecular weight of 148.9 and a boiling point of -72° F. It is used as a fire extinguishing agent. It has proven to be a very effective agent in portable extinguishers for use against Class B (flammable liquids) and Class C (electrical) fires.

Fires are generally extinguished by one of the following actions: cooling, oxygen exclusion (smothering), or mechanical separation of fuel from the oxidizer. However, it is thought by DuPont (4) that FE1301 extinguishes by a chemical action. The halogen compound reacts with the transient combustion products which are responsible for rapid and violent flame propagation. This reaction terminates the combustion chain reaction and thereby stops the flame propagation. There are two different theories to explain the extinguishment process, one based on a free radical process, the other based on ionic activation of oxygen during combustion.

In the free radical theory, a bromine radical is first formed through thermal decomposition of FE1301:

$$CBrF_3 \rightarrow [CF_3]^+ + [Br]^-$$

the bromine radical reacts with hydrogen in the fuel to give hydrogen bromide:

$$R\text{-}H + [Br]^- \rightarrow [R]^- + HBr$$

The hydrogen bromide then reacts with active hydroxyl radicals:

$$HBr + [OH]^- \rightarrow H_2O + [Br]^-$$

The bromine radical may now react with more fuel to repeat the process to remove more active radicals from the fire.

According to the ionic theory, elemental oxygen must be activated by absorbing free electrons before it can react with the fuel. The bromine atom of FE1301 provides a much larger target for the capture of electrons than does oxygen, and thus reduces the probability of oxygen activation.

In both theories, the chain reaction of the fire is broken with relatively small quantities of extinguishing agent.

The tip of the rub ignitor employed to rub against an Inconel 718 sleeve located on the test rig shaft was machined from a 3/16 in. thick Inconel 718 piece with a 1/16 inch thick silver braze material coated over the contact surface. The silver braze material is used by a major engine manufacturer in a labyrinth seal design and was furnished by NASA.

TEST FACILITY

All tests were performed in an existing NASA owned high speed bearing test rig modified on this program to accommodate the requirements for the fire study. The rig operates with SKF owned drive, oil and air systems and controls. The basic test equipment is shown diagrammatically in Enclosure 1 and consists of the following components:

- Test Rig
- Drive System
- Hot Air System
- Lubrication System
- Nitrogen Purging System
- Instrumentation
- Fire Retardant or Freon Systems
- Fire Ignition System
- Oil Recovery System

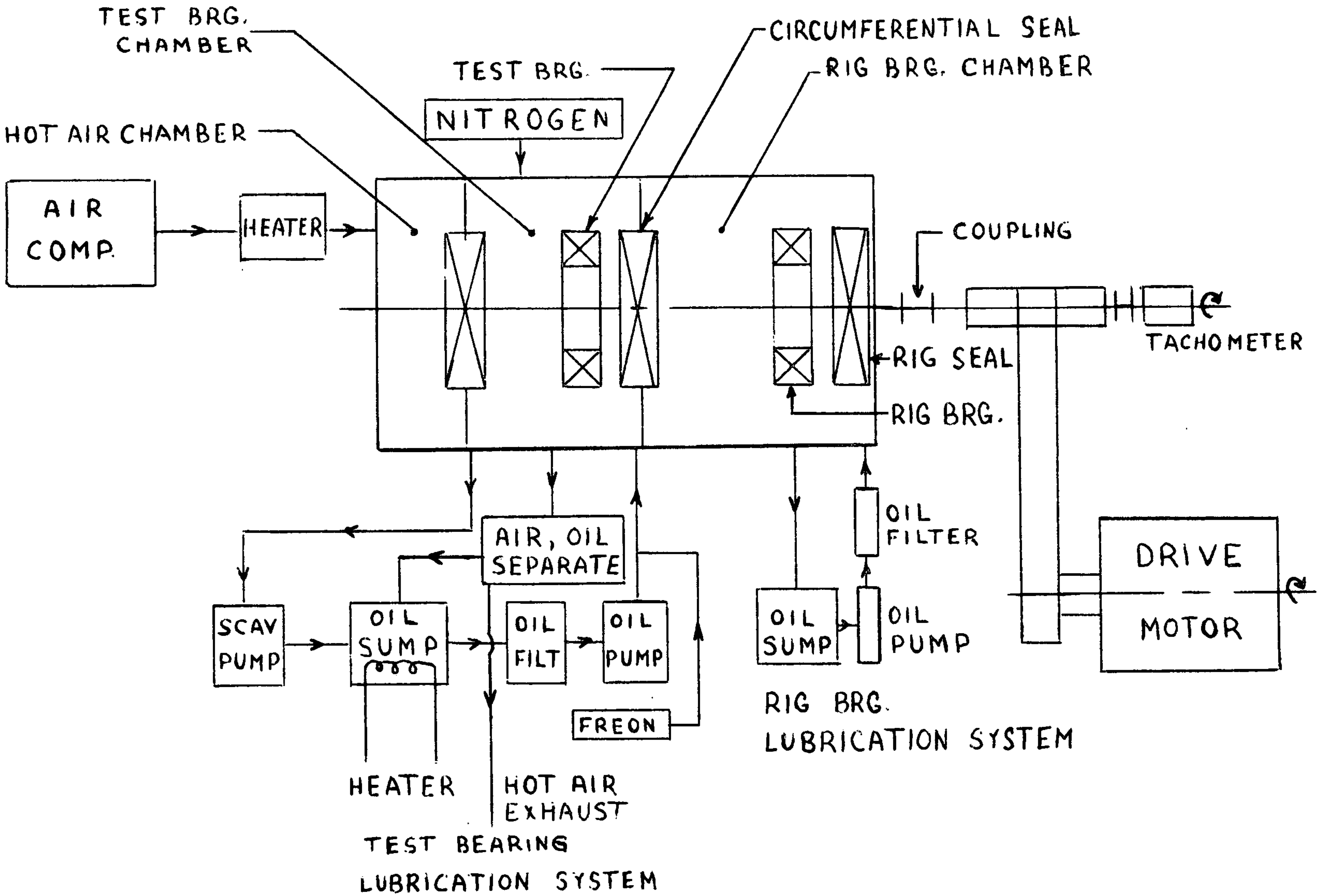
A. Test Rig

The basic test rig is designed to simulate aircraft engine mainshaft designs by avoiding thick sections in the shaft and bearing housings and by introducing flexible sections between the main rig outer housing and the bearing outer rings. This flexibility is intended to simulate to some extent the self-aligning ability of current aircraft engine bearing mounts. The initial design of the rig as used and described in Reference 1 is shown in the assembly drawing in Enclosure 2 with incorporated modifications shown in Enclosures 3 and 4.

The test rig consists of a 12" diameter cylindrical housing in which a hollow shaft of approximately 5" maximum diameter is supported by the test bearing at one end and a cylindrical roller (rig) bearing at the other. The housing itself is mounted in a horizontal position above a table by means of a special support system which maintains the center line height and parallelism with the table while freely permitting both radial and axial thermal expansion. This arrangement is best shown by the isometric sketch in Enclosure 5.

The pedestal is positioned in the plane of the test bearing for optimum rigidity and the sliding ring in the

GENERAL TEST RIG LAYOUT SCHEMATIC



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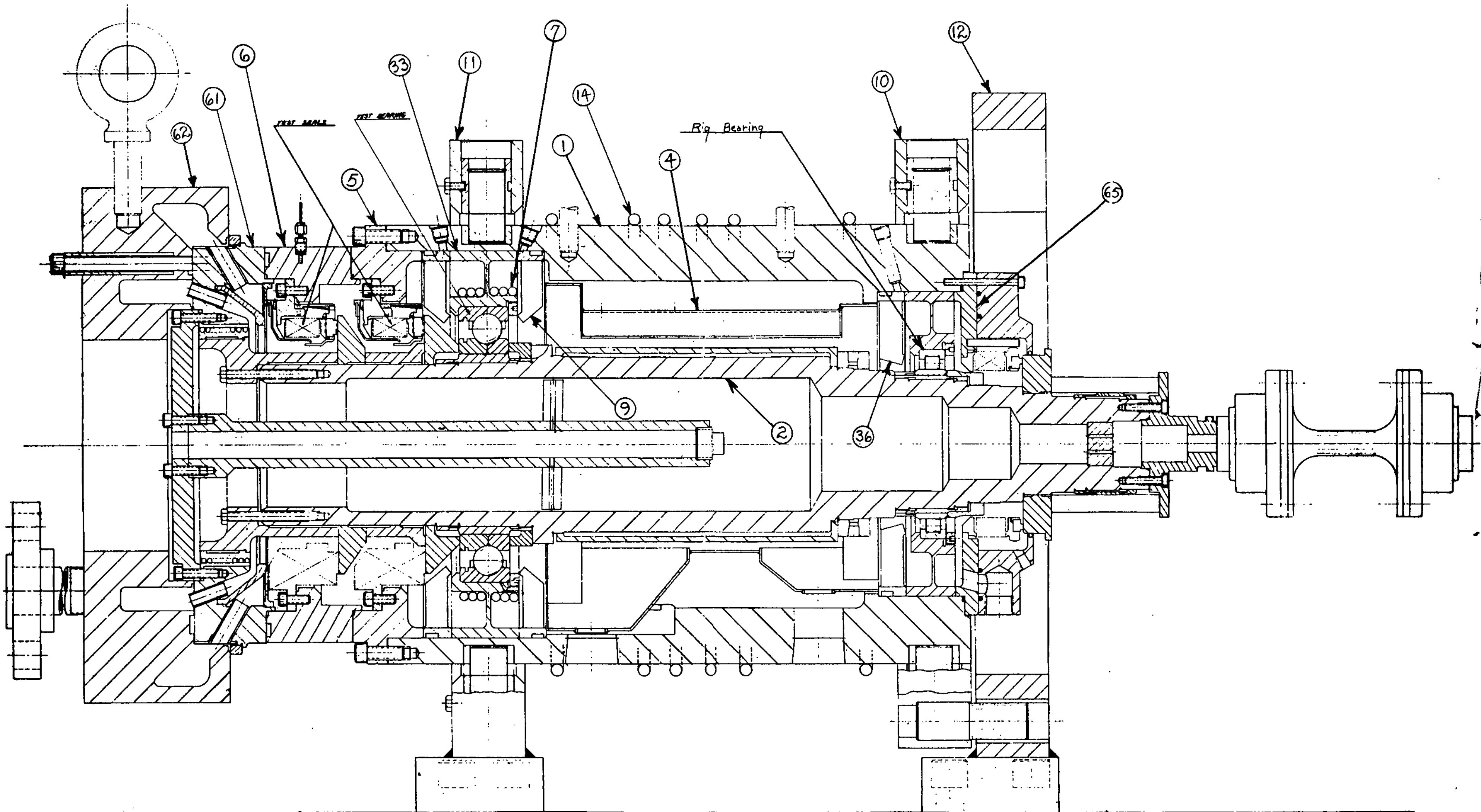
ENCLOSURE 2

STANDARD TEST RIG ASSEMBLY



11-A

11-B

SECTION "A-A"

11-C

ENCLOSURE 3

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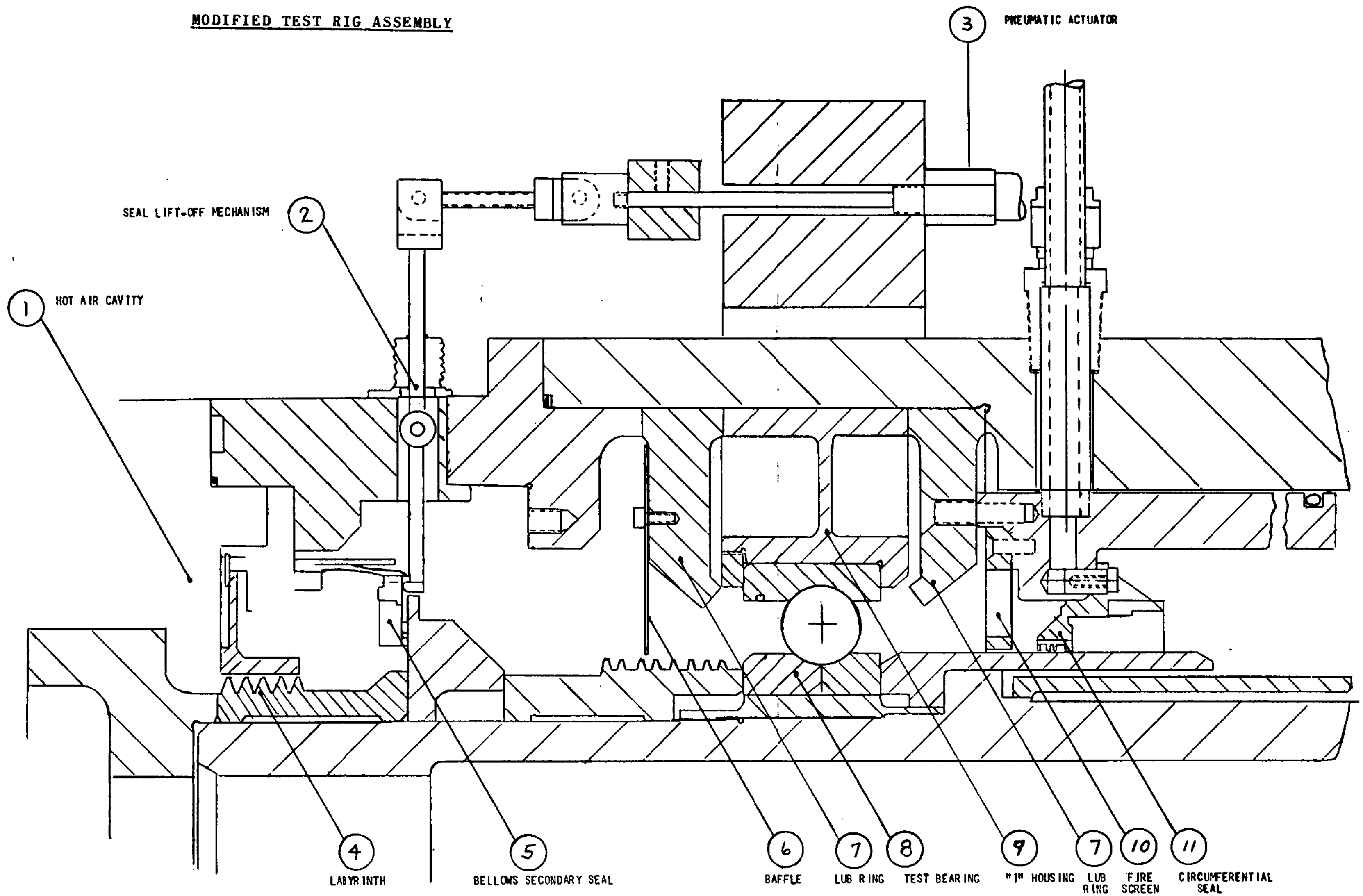
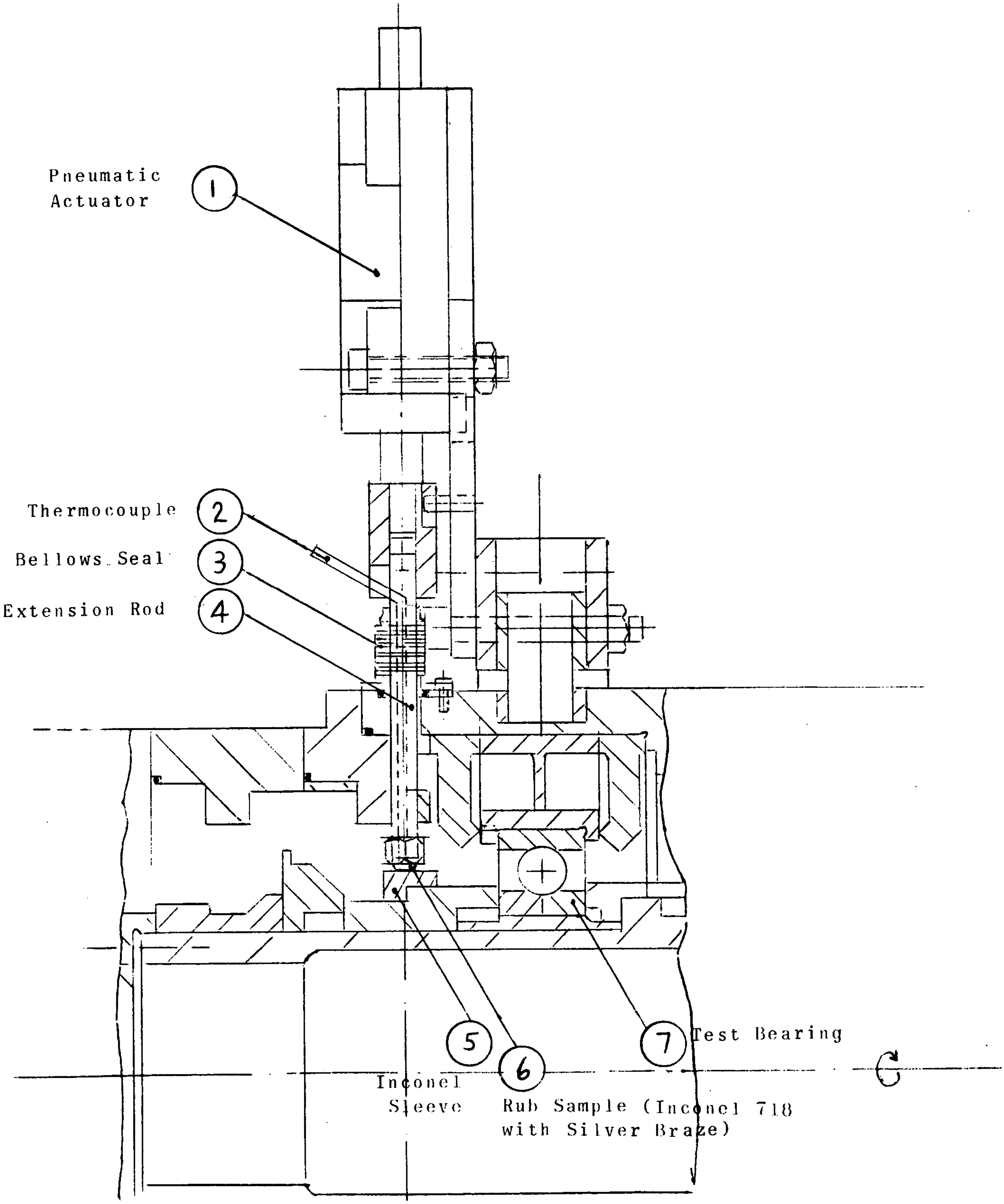
MODIFIED TEST RIG ASSEMBLY



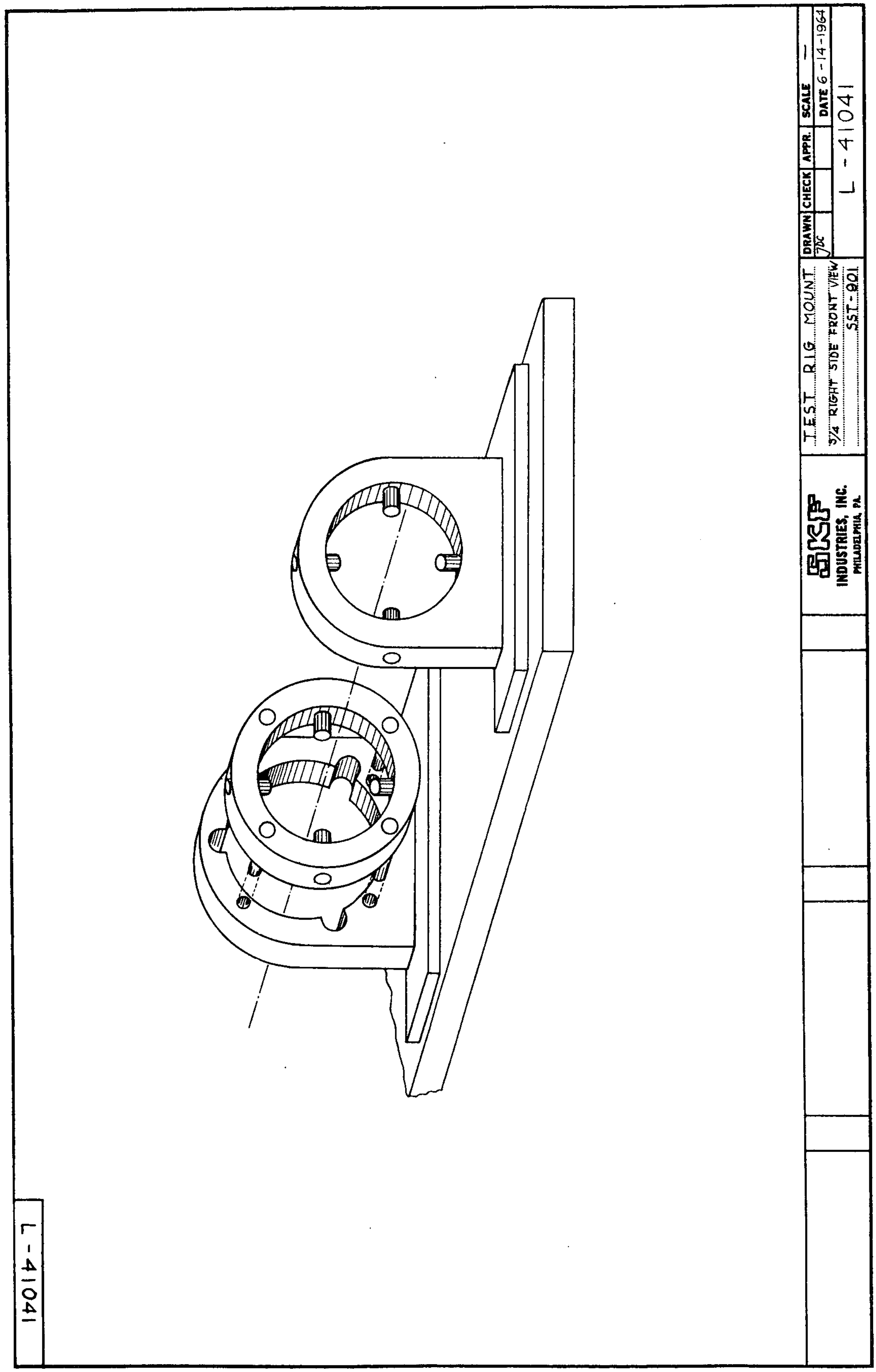
ENCLOSURE 4

RUB IGNITOR MECHANISM



ENCLOSURE 5

ISOMETRIC VIEW OF MOUNTING ARRANGEMENT



plane of the roller bearing. The pedestals are bolted securely to the rig table and also dowelled to maintain alignment.

The inside of the rig is divided into three basic compartments; 1) Hot air chamber 2) Test bearing chamber 3) Rig bearing chamber, see Enclosure 1.

The hot air chamber is that space forward of the bellows seal and is maintained at a pressure necessary to supply the thrust load to the test bearing and hot air flow into the test bearing chamber during lift-off of the bellows seal for fire ignition attempts. Three pneumatically actuated rams which provide lift-off or opening of the bellows seal are mounted circumferentially at 180° increments on the forward pedestal and the actuation linkages enter the hot air cavity through flexible metal seals, see Enclosure 6.

The test bearing chamber (oil sump) is that space between the bellows seal and the circumferential seal and provides the environment in which fire ignition takes place. This chamber accommodates a 125 mm bore ball bearing (test bearing) mounted in a I housing and two lubricant feed rings, one on either side of the bearing. A hot air baffle plate, see Enclosure 6, used to retard the hot air flow into the bearing during bellows seal lift-off is mounted outboard of the lubricant ring located forward of the bearing. Two oil drain holes are located at the base of the chamber housing, one on either side of the bearing and a hot air exhaust port approximately 45° from the top.

The rig bearing chamber, that space between the circumferential and rig seals, contains the roller (rig) bearing which supports the back end of the shaft, the lubricating ring for the rig bearing, the rig bearing housing, and the lubricant drain port.

Electrical resistance heaters are located in axial holes in the main housing to maintain the desired outer ring temperature of the test bearing. Both the ball and roller bearings used to support the rotating shaft are mounted in I shaped housings to provide sufficient flexability to minimize

ENCLOSURE 6

RIG COMPONENTS

Seal and Seal Housing Showing Lift-Off Mechanism

Lubrication Jet Ring and Baffle Plate

shaft-to-housing misalignment forces produced by uneven thermal gradients. The bearings are mounted to the shaft through a specially designed sleeve which compensates for unequal thermal growth between the shaft and bearing bore. This prevents excessive mounting stresses and deflections which would affect the internal clearance in the bearings.

B. Drive System

The test rig shaft is driven by a motor and jackshaft assembly. The variable speed, 50 HP DC drive motor is mounted on an adjustable base and drives the jackshaft through a flat belt. The jackshaft unit consists of a hollow shaft mounted in matched pairs of preloaded angular contact bearings at each end with a 3" diameter removable pulley at the center. The bearings are supported in steel pillow blocks bolted to a rigid base, and are lubricated by a circulating cold mineral oil supply fed to the top cap of each bearing.

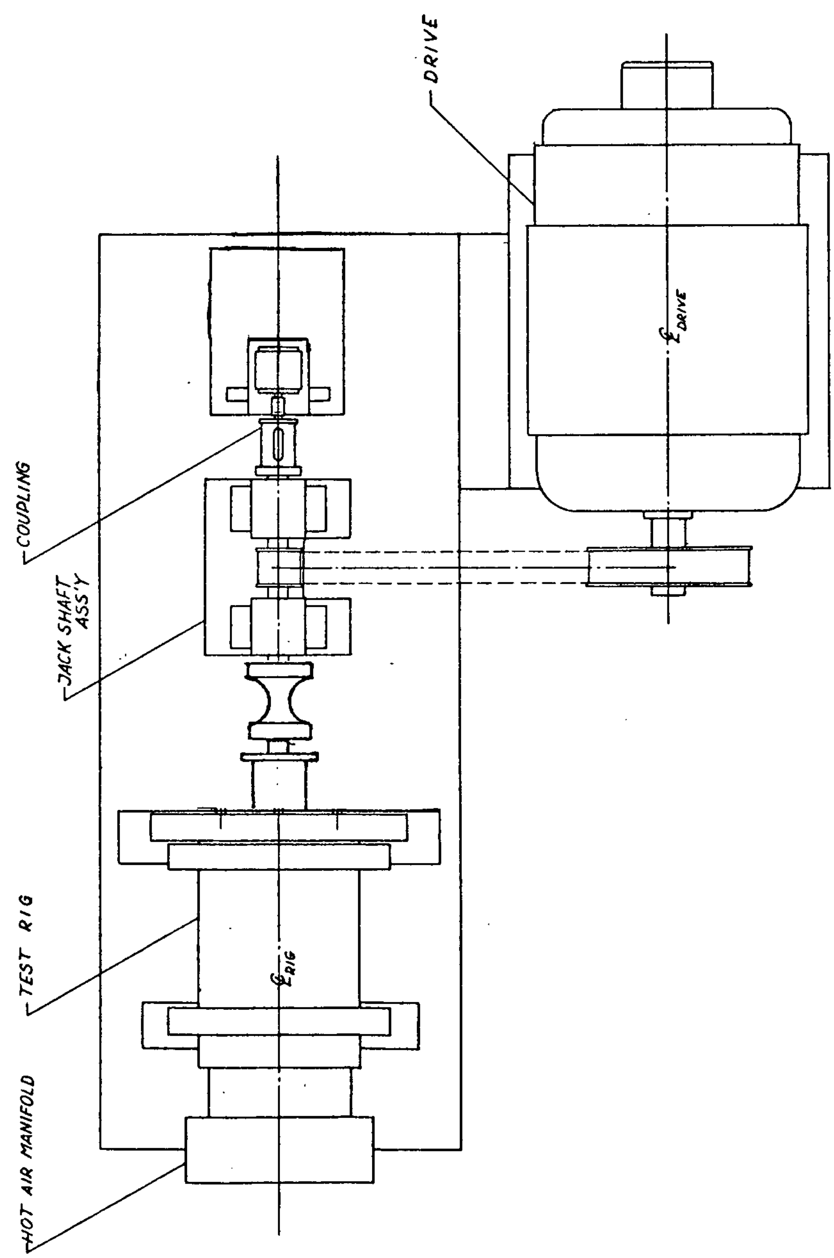
The rig shaft is connected to the jackshaft by a Lovejoy gear coupling. The other end of the jackshaft drives a tachometer through a small flexible coupling. The jackshaft like the rig shaft is dynamically balanced for high speed operation. A schematic of the drive system is presented in Enclosure 7.

C. Hot Air System

A schematic diagram of the hot-air system is shown in Enclosure 8. The air flow commences with the air compressor which has a rated output of 91 scfm at 200 psig. Air feeds directly to a dryer and filter column which reduces the moisture content to a -50° F dew point and the hydrocarbons to 13 parts per million. This clean, dry air then passes to a 20 cu. ft. receiver and hence through a shut-off valve and to a pressure regulator. A pneumatic servo control on this regulator maintains the desired pressure in the rig air chamber. The regulated air then passes through an indicating flowmeter to a 45 kw electrical heater also shown in Enclosure 8, in which the air passes through approximately 22 feet of 316 stainless

ENCLOSURE 7

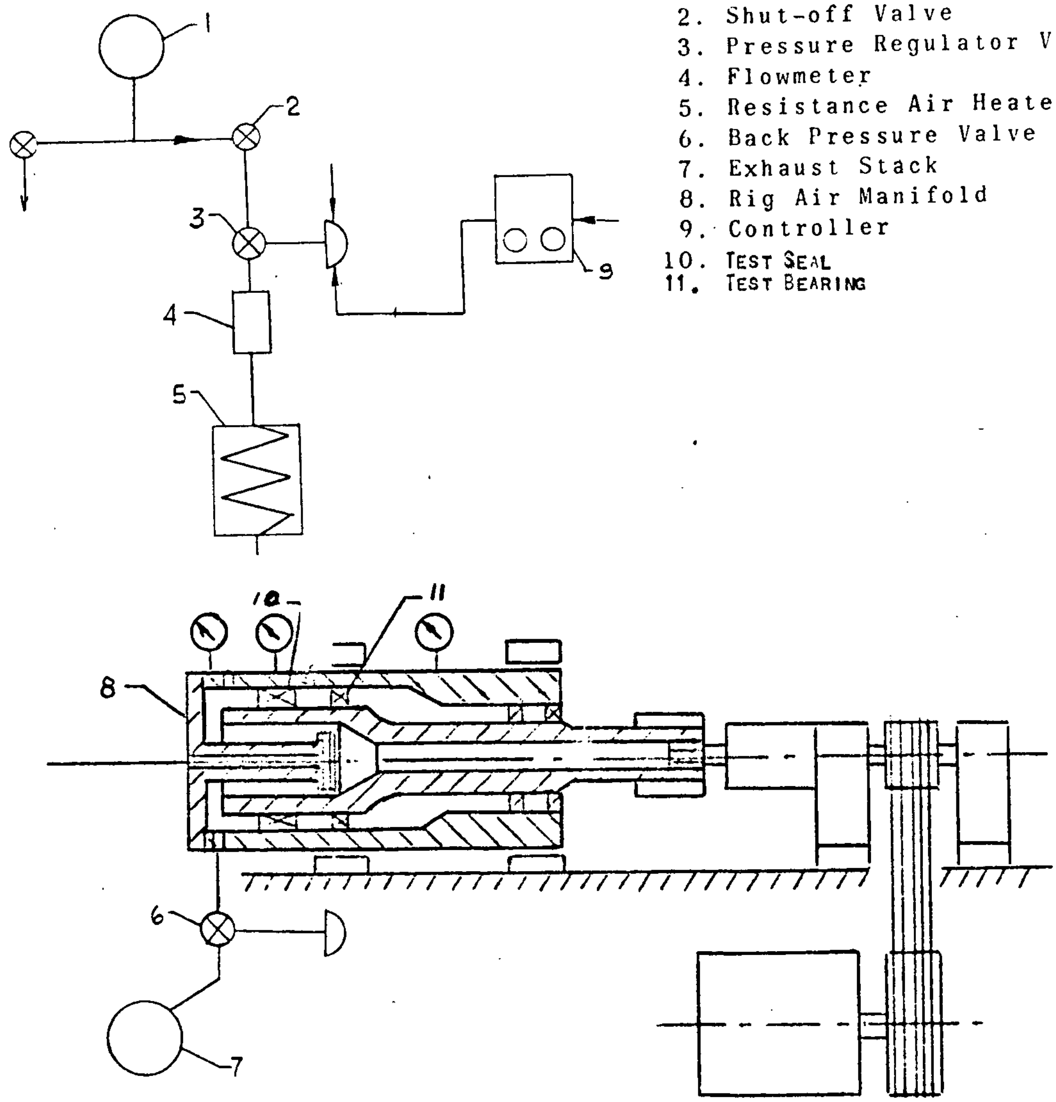
TEST RIG DRIVE SYSTEM



ENCLOSURE 8

SCHEMATIC OF HOT AIR SYSTEM

1. Receiver Tank
2. Shut-off Valve
3. Pressure Regulator Valve
4. Flowmeter
5. Resistance Air Heater
6. Back Pressure Valve
7. Exhaust Stack
8. Rig Air Manifold
9. Controller
10. Test Seal
11. Test Bearing



steel tubing which is radiantly heated by the electric elements, and hence to the rig hot air chamber.

The output of a thermocouple mounted in the hot air line between the heater and rig is fed to the electrical input controls of the 45 kw heater so the desired temperature can be maintained.

Air entering the hot air chamber of the rig is either exhausted through a pneumatically actuated hot air chamber exhaust valve and/or though the bellows seal into the bearing chamber where it exhausts through a hot air port. In either case, the air is then exhausted via a large pipe passing through the test cell wall to a stack.

D. Lubrication Systems

The 125 mm bore ball bearing (test bearing) and the roller bearing (rig bearing) are lubricated by separate lubrication systems. This arrangement was implemented to minimize the safety hazard by using a non-flammable fluid (Krytox) for lubricating the rig bearing and thus preventing the propagation of fires from the test bearing chamber into the rig bearing chamber. The test bearing lubrication system is shown diagrammatically in Enclosure 1. This system was purchased from AR Dervares Co. in accordance with SKF specifications and consists of the following components.

Oil Storage and Heating Tank
Filter Unit
Lubrication Pump
Bypass Valve
Scavange Pump

The test oil is stored and heated by electrical resistance heaters in a 15 gallon capacity, thermally insulated tank with a level indicator and oil temperature sensor. The oil is pumped from the storage tank through stainless steel tubing into a Filterite, six element 10 micron filtering unit by a Viking model 64724 gear pump driven by a 1/2 HP constant speed AC motor. The oil then passes through a Cashco model 460 bypass valve allowing excess oil to return to the storage tank. The oil flowing to the test rig then passes through a pneumatically actuated, variable orifice, flow control valve and then through a Brooks model 103623w-5510A flow meter. The oil leavingthe flow meter is divided equally into two paths each entering one of the two oil manifold rings inside the rig. Each oil manifold ring contains ten equally spaced nozzles (four nozzles plugged to increase jet velocity) which direct the oil flow against the bearing sides. A Viking gear pump, model HL 4724, driven through a variable speed drive by a 3/4 HP AC motor scavenges the oil from the bearing chamber.

The lubrication system provided for the rig bearing is similar in design to the test bearing system with the exception that different components are used and no scavange pump is incorporated in the return line (gravity feed only).

E. Nitrogen Purging System

The need to provide an inert gas for purging fires in the test rig was accomplished by piping a nitrogen supply line directly into the test bearing chamber. The nitrogen is supplied from an outdoor nitrogen station employing atmospheric vaporization of liquid nitrogen. This system which has been used extensively for blanketing test bearings in bearing and lubricant tests (ref. 1) is capable of supplying up to 116 scfm at ambient temperature and at pressures up to 170 psig.

F. Instrumentation

The test rig was instrumented to measure the following parameters:

Hot Air Chamber Pressure
Test Bearing Chamber Pressure
Hot Air Inlet Flow Rate
Test Bearing Oil Inlet Flow Rate
Rig Bearing Oil Inlet Flow Rate
Test Bearing Oil Scavenge Rate
Test Bearing Oil Inlet Temperature
Hot Air Inlet Temperature
Hot Air Temperature Entering Bearing Chamber Exhaust Port
Bearing Outer Ring Temperature
Shaft Speed

A Honeywell Model Y702X21-C39-II-III dual pen pressure recorder was used to measure and record the pressure in the hot air and test bearing chambers. The recorder is located outside the test cell and is actuated through 1/4 inch copper tubes connected to the proper rig chambers. In addition to the recorder, two pressure transducers send electrical signals proportional to pressure to meters located on the instrument console.

The hot air inlet flow rate was measured prior to heating by a Brooks Rotameter model 1140 which is located on the pneumatic console external to the test cell.

The test bearing and rig bearing lubrication flow rates were measured just prior to the lubricants entering the rig. The test and rig bearing lubricant flow rates were measured by a Brooks Armored Rotameter model 103623w-5510A and a Brooks Rotameter model 1110-0903PB1A respectively.

The oil scavenge flow rate from the test bearing chamber is fixed by the shaft speed of the Viking gear pump model HL4724. A calibration of the shaft speed with respect to the variable speed drive control was performed prior to testing and thereafter the scavenge rate was established by the setting on the variable speed drive.

All required temperature measurements were made with iron-constantine thermocouples. All thermocouples leads are wired to a patch panel, outside the test cell, from which it can be connected to a Honeywell strip chart recorder for a continuous record or an Esterline Angus multipoint recorder which records each point approximately once every 72 seconds. During fire study testing, the hot air inlet temperature and the hot air exhausting from the bearing chamber were recorded on the strip chart while all other temperatures were recorded on the multipoint recorder.

The shaft speed was controlled manually by a variable-speed drive and the speed monitored by a tachometer-generator mechanically coupled to the test shaft and producing electrical impulses proportional in number to the rotational speed of the shaft. The output signal was presented on a Hewlett Packard electronic counter model 521CR in cycles per minute.

G. Fire Retardant or Freon System

Two different Freons (Freon 113 and Freon FE1301) were used as fire retardants during the testing. Since the Freon 113 is a liquid and Freon FE1301 a gas at room temperature and atmospheric pressure, two different methods of inserting the retardants into the lubricant were incorporated. In both cases the retardant entered the test lubricant line approximately one foot prior to the line entering the test rig.

The liquid Freon 113 was pumped into the lubricant line after it passes through a Brooks Rotometer model 111008H2B1 by a gear pump variable speed drive and AC motor combination. The pump speed was controlled to obtain the desired flow rate. The Freon FE1301 was forced into the lubrication line by the differential pressure between the Freon line and lubricant line. The Freon line pressure was maintained by a Matheson single stage pressure regulator model 1H-660 attached to the high pressure tank. The flow rate was determined by measuring the weight loss in the storage container during the time period of the test run and converting the weight loss to a liquid volume value. Prior to testing, approximate flow rates were established by calibrating the metering value for various pressure differentials.

H. Fire Ignition System

Two different types of fire ignition devices were incorporated into the test rig to aid in the generation of fires which did not start spontaneously. The first system installed was a spark generator actuated by a 10,000 volts, 23 ma AC signal produced by a Jefferson Electric Co. Ignition transformer operating from a 120 volt 60 cycle input. Two spark generators were installed through the rig housing into the forward section of the test bearing chamber. The ignitor tips were positioned to produce sparking to the hot air baffle plate at 4 and 10 o'clock. An ammeter was installed into the primary circuit of the transformer to detect sparking.

To simulate a real fire ignition hazard, a rub (friction) ignitor mechanism, see Enclosure 3, was incorporated into the test rig to replace the spark ignitor.

This mechanism consisted of a pneumatically actuated ram with a spring return, which is mechanically attached to an extension rod which enters the rig housing through a bellows seal, see Enclosure 3. The end of the extension rod is threaded to permit a tapered bore nut to clamp a special rub material sample to the rod. The rub material is 718 Inconel with a 1/16 inch thick section of silver braze adhered to one surface. This material is used by a major aircraft engine manufacturer in a labyrinth seal and was furnished by NASA for this test.

The extension rod, enters the rig between the air seal and the test bearing baffle plate, moves along a radial line to engage with an Inconel sleeve on the rotating shaft. The rod is guided by two bushings which were incorporated to prevent binding and excessive bending of the rod during operation. A chromel-alumel thermocouple extends down the hollow rod and bears against the inner surface of the rub sample to permit temperature measurement.

It was assumed during the design of the mechanism that 10% of the heat generated between the ignitor tip and the shaft sleeve would enter the tip and that the coefficient of friction between the two surfaces would be 0.15. Assuming these conditions, the temperature of the ignitor tip would increase approximately 1200° F in thirty seconds when the shaft is rotating at 14,000 rpm and a actuator-force of 68 lbs is applied. Since the cooling effect of the air and lubricating oil impinging on the rubbing surfaces could not be evaluated a pneumatic actuator capable of applying a 500 lb. force was selected. Therefore, localized temperatures higher than 2000° F could be theoretically obtained. It was also established that a 500 lb. radial load on the test bearing should not affect its performance.

I. Oil Recovery System

The high rate of test oil loss, carried by the hot air exhausting from the bearing chamber, during the initial testing dictated the use of an oil recovery system. The system incorporated a large 3 x 2 ft. separator tank assembled onto the bearing chamber hot air exhaust line and a return line attached directly to the test bearing lubrication supply tank. The large size of the tank and a baffle plate located between the inlet and exhaust parts converts the high velocity of the gas carrying the oil to a static pressure allowing the oil to migrate to the bottom of the tank. The separated oil accumulated in the bottom of the tank is returned to the supply tank by a positive displacement pump located on top of the tank. The hot air flowing through the tank prevents excessive cooling of the oil.

TEST PROCEDURE

Four types of tests were performed during the program with only minor modifications to the test procedures between each type. The four basic types were:

1. Baseline tests - spontaneous ignition

2. Baseline tests - spark ignition

3. Fire retardant tests - spark ignition

4. Baseline tests - rub (friction) ignition

The specified conditions under which tests were performed were:

Test oil inlet temperature - 250 to 380° F

Test oil flow rate - 1 to 2 gpm

Test bearing outer ring temperature - 350 to 550° F

Hot air inlet temperature - 800 to 1100° F

Shaft rotational speed - 4000 to 14,000 rpm

Testing was initiated after obtaining minimum test conditions and temperatures had stabilized for approximately ten minutes. The air seal was then lifted off, unless sufficient leakage already existed, and the ignition source activated for a period of 60 seconds or until a fire ignited. If a fire was ignited the nitrogen purging system was immediately activated and the bearing chamber purged with nitrogen gas.

If no fires were ignited, as determined by an increase in the hot air exhaust temperature, the test conditions were stepwise increased to more and more severe conditions until a fire was ignited or maximum test conditions or rig limitations were reached. The specific test parameter or combination of test parameter changed between each test run and varied for each individual test.

The following procedure was followed to bring the test rig to test conditions.

1. Start air compressor and adjust pressure to 190 - 200 psi.

2. Set temperature controller for test bearing and rig bearing storage tanks at 500° F and 150° F respectively. Start circulation of test bearing oil through filter, pump and bypass valve. Actuate imersion heaters in test bearing storage tank and adjust reostats to obtain a current of 12 amps in each heater. Rig bearing lubricant heaters are automatically actuated when controller is set.

3. Actuate rig housing heaters and set temperature control at 400° F.

4. When test oil temperature reaches 280° F, initiate hot air flow through the test bearing chamber. Set air temperature controller at 500° F and adjust flow rate to 20 to 30 scfm by regulating hot air manifold pressure. The hot air flow aids in warning the rig components and the oil-air separator tank to minimize oil cooling when circulation through rig is initiated.

5. Start circulation of test oil and rig bearing oil through rig when test oil temperature reaches 320° F. Adjust test oil flow rate to 1 gpm and scavenge rate to 15 gpm.

6. Adjust test bearing inlet pipe heaters to 12 amps.

7. Turn on jack shaft lubrication system.

8. Start shaft rotation and adjust speed to 5000 rpm.

9. Increase hot air temperature to 1000° F.

10. Continue operation until test conditions are obtained.

After testing was terminated with each lubricant the rig was disassembled and components inspected and cleaned. The test oil system was drained and the lines flushed first with Solvasol 6 and then Naphtha until all visable traces of oil were eliminated. The piping was then disassembled and the lines dried by pressurized air. After reassembly the system was replenished with 15 gallons of the next test lubricant.

RESULTS AND DISCUSSION

A. Baseline Tests - Spontaneous Combustion

Considerable amount of effort was expended during the first test phase of this program to establish if fire would ignite spontaneously in the test bearing sump and/or bearing chamber hot air exhaust. Several baseline tests were performed with additional tests of various components or systems.

It has been the observation of one gas turbine engine manufacturer that spontaneous combustion occurred in the bearing sump when the rubbing seal opened allowing excessive quantities of hot air to pass into the sump. Another manufacturer indicated that spontaneous combustion would most likely occur in the bearing chamber vent line as the result of high surface temperatures at that point.

Initial tests were conducted to produce spontaneous combustion in the sump by opening the rubbing seal, once test conditions were obtained, to allow the hot air to mix with the bearing lubricant. Mobil Jet II lubricant was used throughout the spontaneous combustion testing.

During these tests, rig limitations were encountered which required rectification before any positive conclusions could be established. These modifications included: 1) a 25 percent increase in the heat supplied to the test lubricant supply tank and the incorporation of calrod type heaters and insulation on the inlet lubricant line to increase lubricant inlet temperature; 2) A piston ring secondary seal and rig hardware modification to permit its use in place of the bellows secondary seal which was unstable and permitted excessive leakage; 3) The incorporation of a Monel sheet-metal baffle plate in front of the test bearing to protect it from direct impingement of the hot air which had resulted in a thermal inbalance bearing failure.

Testing conducted after these modifications resulted in the conclusion that spontaneous combustion would not occur in the test rig bearing sump even when specified conditions were surpassed.

Additional tests were performed during which the bearing chamber vent line was heated by Calrod type heaters. Although fires were ignited external to the vent line. no internal fires were ignited even when pipe temperatures between 1000 and 1100° F and gas temperatures of 650° F were imposed. This indicated that the oil-air mixture in the line was either too rich or two lean to support combustion.

B. Esso 4040 Baseline And Fire Retardant Tests

A baseline test was initially performed with Esso 4040 lubricant to establish conditions under which fires could be ignited by the electric spark. A second test was performed to evaluate the retarding effect of Freon 113 when mixed with the lubricant. In both tests the air leakage through the seal was sufficient to obtain the desired flow rates by varying the hot air chamber pressure; therefore, it was not necessary to lift off the seal.

During the baseline test five fires were ignited in 19 attempts under a variety of test conditions, see Enclosure 9. These were readily identified by noting the temperature increase of the thermocouple located near the hot air exhaust orifice in the bearing chamber and the heavy gray-white smoke exhausting from the vent line outside the cell. A thermocouple located down stream in the vent line showed much slower temperature increase indicating that fires were concentrated in the bearing compartment and tended to propagate into the vent slowly. An optical (ultraviolet) fire sensing device attached to an opening in the bearing chamber proved unsuccessful in detecting the fires. Although the sensor was easily activated by the match flame during pretest checks, the oil film on the inner lens and the dense smoke were apparently sufficient to attenuate the ultraviolet light to an undetectable level. No major effort was spent on improving the flame detector performance since the thermocouple was completely adequate. However, an ultraviolet flame detector may still be a viable method of detecting fires in the bearing chamber if suitably modified.

ENCLOSURE 9

ESSO 4040 BASELINE TEST DATA

						Lubricant			Hot Air							
Run No.	Spark Time	Freon (%)	Fire	Shaft Speed (RPM)	Brg. Temp. (°F)	Temp In (°F)	Flow Rate (GPM)	Scavenge Rate (GPM)	Manifold Pressure (PSI)	Flow Rate (SCFM)	Est. Flow Brg. Cav. (SCFM)	Manifold Temp (°F)	Composit Temp (°F)	Vent Inlet No Fire (°F)	Vent Inlet Fire (°F)	Remarks
1	10 Sec	-	No	10,000	385	330	1	15	20	23	15	400	1115	340		
2	30 Sec	-	No	10,000	385	330	1	15	20	23	15	600	1315	340		
3	60 Sec	-	No	10,000	385	330	1	15	20	23	15	730	1345	360		
4	100 Sec	-	No	10,000	385	340	1	15	20	23	15	750	1395	370		
5	60 Sec	-	No	10,000	385	340	1	15	30	-	-	840	1465	390		
6	5 Min	-	No	10,000	400	340	1	15	30	-	-	900	1640	400		
7	3 Min	-	No	10,000	420	340	1	15	40	40	26	990	1750	430		
8	2 Min	-	Yes	10,000	450	340	1	15	60	45	30	950	1740	510	1120	
9	3 Min	-	No	1,000	490	350	1	15	60	45	30	1070	1910	700		
10	2 Min	-	Yes	6,000	470	350	1	15	60	45	30	940	1760	640	1120	
11	50 Sec	-	Yes	6,000	400	350	1	15	60	45	30	930	1680	680	700	
12	20 Sec	-	Yes	6,000	420	320	1	15	60	45	30	910	1650	560	620	
13	100 Sec	-	Yes	8,000	460	320	1	15	60	45	30	900	1680	560	640	Not Self-Sustaining
14	90 Sec	-	No	6,000	450	325	1	15	60	45	30	900	1675	600		
15	5.5 Min	-	No	6,000	450	325	1	15	60	45	30	890	1665	600		
16	3 Min	-	No	6,000	445	325	1	7	60	45	30	925	1695	600		
17	14 Min	-	No	6,000	445	330	1	7	60	45	30	950	1720	600		
18	6 Min	-	No	6,000	470	330	1	7	60	45	30	975	1775	630		
19	3 Min	-	No	,500	475	330	1	7	60	45	30	990	1795	700		

It was evident from this test that fires could be readily ignited in Esso 4040 by using the spark ignitor when sufficiently severe conditions existed. The least severe condition under which a fire could be ignited was:

Outer ring bearing temperature - 420° F

Lubricant inlet temperature - 320° F

Hot air inlet temperature - 910° F

These conditions are similar to conditions which could be expected in a bearing sump; thus showing that the presence of an ignition source can ignite fires in an engine bearing sump if the proper oil-air mixture exists. However, the fires generated were quite mild and propagated slowly. One fire was not self-sustaining after the spark was turned off.

Because of the large number of interacting variables, it was impossible to obtain the exact same condition in replicate tests. Criteria were needed by which the overall severity of the test condition could be evaluated and by which comparisons between test runs and different tests could be made. A reasonable parameter appeared to be the total heat energy within the bearing chamber. However, since the hot air flow rate and the bulk temperature of the chamber components were not well established, a less accurate but more easily determinable factor was used; the composite temperature or sum of the bearing outer ring, hot air and oil inlet temperatures. This is not meant to imply equivalent influence of each part of the composite. The least severe condition, based on this criterion, at which fires could be ignited in Esso 4040 using a spark ignitor was 1650°F for the sump geometry used.

In each case where the fires were self-sustaining, the nitrogen gas purging system was used to extinguish the fires. An approximate one second blast of nitrogen, controlled manually by a hand operated valve was sufficient in all cases to put out the fire.

A second series of tests were performed under similar conditions with the Esso 4040 lubricant and varying percentages by volume of a retardant (Freon 113). The Freon 113 was pumped directly into the test lubricant line in a liquid state approximately one foot before it entered the test rig.

Seven test runs were first performed in the absence of Freon, see Enclosure 10, to insure that conditions existed in which fire could be ignited. It was noted during these preliminary test runs that when the estimated hot air flow rate through the bearing chamber was below 20 scfm fires could not be ignited even though conditions were more severe than those under which fires could be ignited in the previous test. This is equivalent to 36 air changes per minute in the bearing chamber. This condition indicates that with a properly functioning seal where the hot air leakage rate is below 5 scfm the oil-air mixture may be too rich to support combustion. Labyrinth seals are likely to allow enough air leakage to support combustion under most conditions of engine operation.

The air flow rate through the bearing chamber had to be estimated since the inlet flow to the hot air chamber exhausts through both the hot air chamber and bearing chamber exhaust lines and the gas flow meter inserted in the bearing exhaust line was rendered inoperative by the large quantity of oil swept out with the hot air. This estimate was based on the valve settings in the exhaust lines. It was necessary to maintain the hot air chamber exhaust valve partially open to obtain stability in the seal and thus a uniform flow of hot air.

Five test runs were made using Freon 113 as a retardant. The first run was performed with a 1% by volume of Freon with respect to the lubricant which was flowing at a rate of 1.2 gpm. During this check no retardant effect was produced with respect to ignition as determined by spark time required to produce ignition. However, the propagation or severity of the fire seemed to be somewhat curtailed as determined by the temperature rise of the exhausting gas.

The four additional retardant tests were performed with 5% Freon. In all cases, it was possible to ignite fires but only one was self-sustaining after the spark was turned off. In the three tests which were not self-sustaining the fires were quite mild.

ENCLOSURE 10

ESSO 4040 AND FREON 113 FIRE RETARDANT TEST DATA

						Lubricant			Hot Air							
Run No.	Spark Time	Freon (%)	Fire	Shaft Speed (RPM)	Brg. Temp. (°F)	Temp In (°F)	Flow Rate (GPM)	Scavenge Rate (GPM)	Manifold Pressure (PSI)	Flow Rate (SCFM)	Est. Flow Brg. Cav. (SCFM)	Manifold Temp (°F)	Composit Temp (°F)	Vent Inlet No Fire (°F)	Vent Inlet Fire (°F)	Remarks
1	10 Sec	-	No	10,000	400	350	1.2	13	40	32	20	1000	1750	480		
2	30 Sec	-	No	10,000	400	350	1.2	13	40	32	20	1000	1750	480		
3	60 Sec	-	No	10,000	400	350	1.2	13	40	32	20	1000	1750	480		
4	60 Sec	-	No	10,000	400	350	1.2	13	40	32	20	1000	1750	480		
5	20 Sec	-	Yes	10,000	400	350	1.2	13	50	40	26	1100	1850	600	>1500	
6	3 Sec	-	Yes	10,000	425	355	1.2	13	50	42	28	1100	1880	650	>1500	
7	2 Sec	-	Yes	10,000	440	260	1.2	13	50	42	28	1100	1900	680	>1500	
8	1 Sec	1%	Yes	10,000	440	320	1.2	13	40	39	26	1100	1860	700	1370	
9	30 Sec	-	No	10,000	400	220	1.2	13	50	40	26	800	1420	400		
10	2 Sec	-	Yes	7,000	470	390	2.0	13	50	40	26	1100	1960	580	1020	
11		-	Yes	7,000	440	390	2.0	13	50	40	26	1120	1950	650	940	
12	0.5 Sec	-	Yes	7,000	440	395	2	13	50	40	26	1120	1995	680	1200	
13	3.5 Sec	-	Yes	7,000	480	395	1	7	50	41	26	1120	1995	670	1350	
14	2 Sec	5%	Yes	7,000	460	230	1.5	7	50	41	26	1120	1810	700	1120	Not Self-Sustaining
15	5 Sec	5%	Yes	7,000	450	230	1.5	7	50	41	26	1120	1800	700	800	Not Self-Sustaining
16	5 Sec	5%	Yes	7,000	450	230	1.5	7	50	41	26	1120	1800	700	800	Not Self-Sustaining
17	15 Sec	5%	Yes	7,000	450	230	1.5	7	50	41	26	1120	1800	700	1000	

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Although it appeared that greater concentrations of Freon 113 would be successful in preventing fires, which retarding mechanism (cooling, smothering, or chemical) was responsible was not definitely established. It was speculated to be either chemical in nature or simply the cooling of the inlet oil.

A fire baffle (0.030 inch thick monel sheet) incorporated prior to these tests on the hot air side of the test bearing was successful in preventing bearing thermal seizure, that had occurred on one occasion in prior testing due to the hot air impinging directly on the bearing. Also, the baffle prevented fires from propagating to the bearing. The baffle plate was attached to the back of the oil nozzle ring and eliminated all openings into the test bearing except a 0.125 inch radial gap around the shaft and a 1 in. sq. hole on the outer edge to permit oil flow into the drain-line and the section of the bearing chamber where fires were ignited.

Initially, the high flow rate of test oil, 0.25 to 0.5 gpm escaping through the bearing chamber hot air vent limited test time between shutdowns for oil replenishment to approximately 35 minutes. The shutdowns were time consuming and costly. To eliminate the shutdowns, a oil-air separator was incorporated in the bearing chamber exhaust line with provisions for pumping the oil back to the storage tank before additional testing was performed.

An inspection of rig components following the testing revealed the following:

1. The inside (side adjacent to the test bearing) lower half of the baffle plate was covered with heavy coking resulting from the high temperatures in the area of the oil drain where oil was plentiful.

2. Light coking on the bearing cage faces and the inner and outer ring outside of the ball track.

3. A deposit of soot on the bore of the air seal housing in a small area adjacent to the spark ignitor.

4. The bearing I - housing was heavily coked but no soot was evident which indicates that the fires did not propagate past the baffle plate or subsequent oil flow removed all soot which may have accumulated.

5. The shaft was covered with a thin layer of varnish.

6. The seal carbon face had started to disintegrate and small amounts of the carbon could be removed by light rubbing.

The carbon material, CDJ83, is designed for operation at lower temperatures than those of this investigation. With the presence of fires in the rig and the hot air passing through the seal breakdown of the carbon could be expected.

7. A microscopic examination of the running surfaces of the bearing showed no abnormal conditions.

In general the components were in good condition, except the seal, but required cleaning. Photographs of the seal housing and baffle plate, and the seal as removed from the test rig are shown in Enclosure 11.

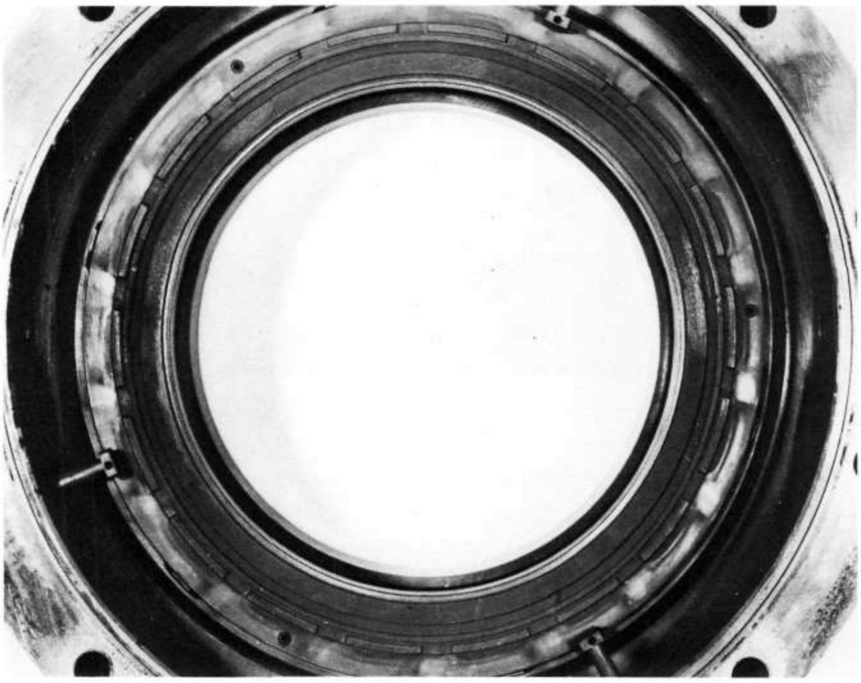
C. Mobil Jet II Baseline And Fire Retardant Tests

Twenty-four baseline test runs were made with the Mobil Jet II lubricant under a variety of test conditions, see Enclosure 12. During the test, air leakage through the air seal was again high and seal lift-off was not required for ignition attempts. The flow rate was controlled by varying the pressure in the hot air manifold.

Testing was initiated with major test conditions (bearing temperature, oil inlet temperature and hot air inlet temperature) slightly below those under which fire were ignited with Esso 4040. During the first six test runs, during which test conditions were progressively made more severe until they surpassed fire ignition conditions for Esso 4040, no fires were ignited. Without further changes in test conditions the spark ignitor actuated was charged from #1 to #2, see Enclosure 13, and fires were ignited in the following two runs. An

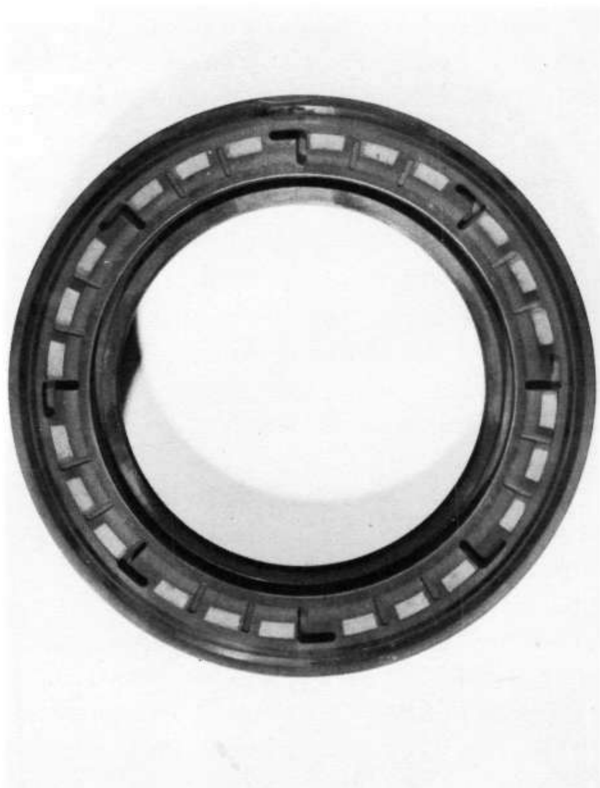
ENCLOSURE 11

SEAL COMPONENTS AND BAFFLE PLATE AS REMOVED FROM RIG AFTER ESSO 4040 TESTING



Carbon Nose Piece And Housing

Baffle Plate In Rig Housing Sector



Carbon Nose Piece

ENCLOSURE 12

MOBIL JET II BASELINE TEST DATA

Run No.	Spark Time (sec)	Freon (%)	Fire	Speed (RPM)	Brg. Temp. (°F)	Lubrication: Temp In (°F)	Lubrication: Flow Rate (GPM)	Lubrication: Scavenge Rate (GPM)	Hot Air: Manifold Pressure (psi)	Hot Air: Total Flow Rate (SCFM)	Hot Air: Manifold Temp (°F)	Composit Temp (°F)	Vent Inlet No Fire (°F)	Vent Inlet Fire (°F)	Remakrs
1	60	-	No	7000	405	330	1.0	15	40	32	900	1635	630		Ignitor #1
2	60	-	No	7091	410	340	1.0	15	40	33	950	1700	690		
3	60	-	No	7121	420	340	1.0	15	40	35	1000	1770	730		
4	60	-	No	7123	430	350	1.0	15	30	31	1000	1780	710		
5	60	-	No	7188	420	350	1.0	15	20	24	1000	1770	660		
6	60	-	No	7159	435	355	1.0	15	50	39	1020	1810	740		
7	9	-	Yes	7150	435	360	1.0	15	50	39	1020	1815	700	>1500	Switch to Ignitor #2
8	2	-	Yes	7002	450	360	1.0	15	50	42	1020	1830	770	>1500	
9	60	-	No	5100	460	360	1.0	15	50	42	1020	1840	790		
10	2	-	Yes	7200	460	360	1.0	15	50	42	1020	1840	790	>1500	
11	45	-	No	4400	490	360	1.0	15	50	42	1020	1870	790		Increased Speed With Spark On
		-	Yes	5300										>1500	
12	60	-	No	7177		360	1.0	15	40	35	1020		780		Increaseb Flow With Spark On
	22	-	Yes						50	42				1430	Fire 22 sec After Increased Flow
13	55	-	Yes	7095	470	360	1.0	15	40	35	1020	1850	780	>1500	
14	120	-	No	7100	490	360	1.0	15	30	29	1020	1870	780		
15	60	-	No	7100		360	1.0	15	30	29	1020		770		Same Conditions as 14 Tried Again
16	35	-	Yes	10000	470	360	1.0	15	30	29	980	1810	730	1170	Temp. Increase Very Slowly
17	37	-	Yes	7000	460	350	1.0	15	30	29	900	1710	760	1020	Temp. Increase Very Slowly
18	47	-	Yes	7000	490	360	1.0	15	30	29	900	1750	750	1080	
19	120	-	No	7000	470	350	1.0	15	20	22	890	1710	730		
20	60	-	No	7000	470	350	1.0	15	20	22	890	1710	730		Same Conditions as 19
21	120	-	No	7000	460	360	1.0	15	30	29	880	1700	680		
22	60	-	No	7000	460	360	1.0	15	40	36	880	1700	700		
23	60	-	No	7000	460	360	1.0	15	50	45	880	1700	700		
24	120	-	No	7000	460	360	1.0	15	60	53	890	1710	720		

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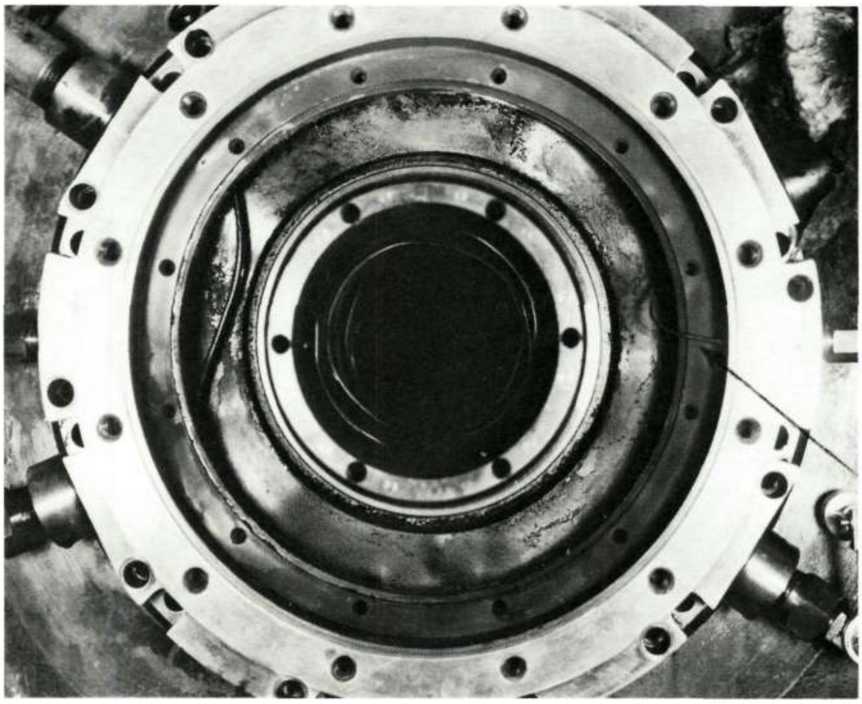
ENCLOSURE 13

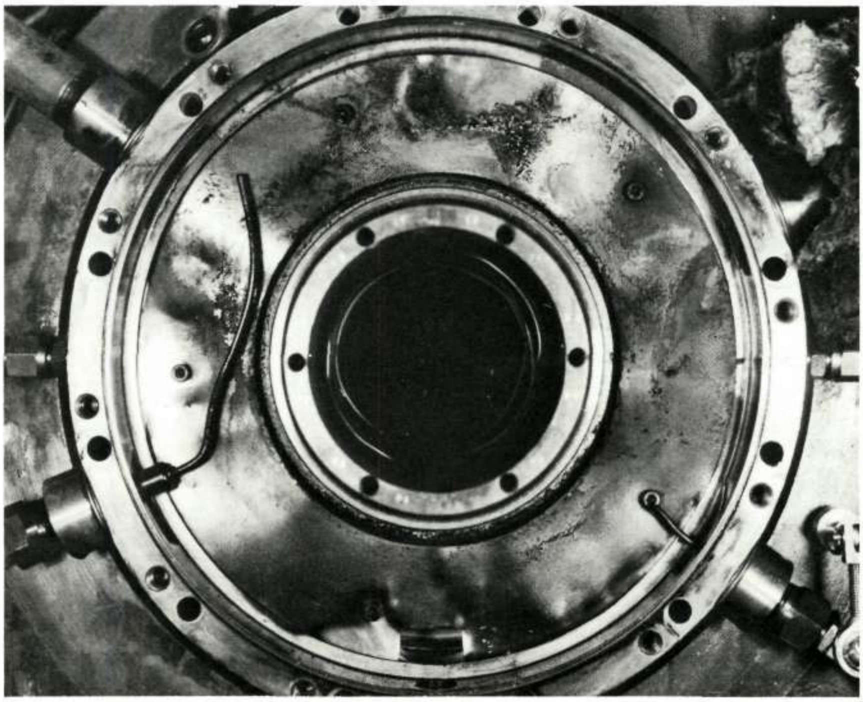
PARTIALLY DISASSEMBLED RIG
AFTER MOBIL JET II TESTS



Exhaust
Air
Thermocouple

Hot Air Cavity and Seal Removed

Ultra-
Violet
Flame
Detector



Bearing
Cavity
Exhaust

Spark
Ignitor #1

Spark
Ignitor #2

Seal Housing Removed
Showing Baffle Plate

ammeter located in the primary circuit of the spark generator transformer was used to give assurance of spark generation in all tests. The short spark time prior to ignition and the increase in exhaust air temperature during runs 7 and 8 showed that conditions were sufficient to permit rapid ignition and propagation of a fire around ignitor #2. Indications were that the oil-air mixture within the chamber is not homogenous throughout and combustable and incombustable mixtures can exist at various locations depending on the flow path of the air and oil.

The shaft speed was decreased to 5100 rpm for run #9 while maintaining other variable constant. No fire could be ignited. With the shaft speed increased to 7200 rpm a fire was ignited in 2 seconds.

To further evaluate the effect of shaft speed on fire ignition the shaft speed was decreased to 4400 rpm. At this speed a fire could not be ignited after a spark time of 45 seconds. The speed was then increased with the spark generator activated, and a fire was ignited at 5300 rpm giving further evidence of the effect of speed on conditions within the bearing chamber.

Additional tests were performed to evaluate the effect of hot air inlet temperature. Although some inconsistencies were observed which could be attributed to uncontrolled conditions, oil-air ratio and flow paths, within the rig, it was established that no fire could be ignited when the hot gas temperature was below 900° F. Fires ignited with air temperatures between 900° F and 1000° F were very small and propagated slowly as determined by the exhausting air temperature. Evaluating the bearing chamber composite temperature showed that at values beteen 1710 and 1810° F only minor fires were started, above 1810° F fast propagation occurred, see Enclosure 12.

The second test was performed with Mobil Jet II to evaluate the retarding effects of Freon FE1301. Fire extinguishing effectiveness and toxicity of some Freon compounds are given in Appendix A.

The retardant test was performed in the same manner as the previous test. Test conditions were first established which were identical to those under which fires could be readily ignited in the baseline test. Test runs were then performed in the absence of the retardant to insure that fires could be started with the spark ignitor. After the fires were extinguished, retardant test runs were then performed under identical test conditions with the exception that the retardant decreased the lubricant inlet temperature as shown in the test data tabulated in Enclosure 14.

Four sets of retardant tests were performed with retardant to lubricant flow rate ratios of 2.64, 8.8, 8.8 and 10.6 percent by volume. The lubricant flow rate was maintained at 1 gal/min throughout the test runs.

In the first test set, three fires were ignited in the absence of the retardant and three ignited in the presence of 2.64 percent by volume of the retardant. In all cases the fires were quickly ignited and self-sustaining. However, the fires did not propagate as rapidly in the presence of the retardant. It was, therefore, expected that greater quantities of the retardant might be sufficient to prevent fires. Therefore, the second set of test runs were made with the Freon flow rate increased to 8.8 percent.

Prior to performing the second set of tests, difficulty was encountered during several test runs in obtaining fires in the absence of the retardant. The shaft speed had been decreased to 6000 rpm during these runs because of high bearing temperatures. When the shaft speed was increased back to 7000 rpm fires were again readily ignited.

During the second set of tests, two fires were ignited in the absence of Freon and two with a 8.8 percent by volume of Freon. In all runs, fires were ignited within one second, propagated rapidly and were self-sustaining. The Freon had no apparent effect on retarding or preventing ignition of the fires. The third set of tests was a repeat of the second set with 8.8 percent by volume of Freon. The fires were quickly ignited and propagated rapidly. Again no retarding effect was observed. The fourth set of tests was performed with 10.6 percent by volume of Freon. Fires were ignited in only three of the four runs made with Freon and in only one run was the fire self-sustaining which indicates a retardation.

ENCLOSURE 14

MOBIL JET II & FREON FE 1301 FIRE RETARDENT TEST DATA

RUN NO.	SPARK TIME (SEC)	FREON (%)	FIRE	SPEED (RPM)	BEARING TEMP. (°F)	LUBRICANT TEMP. IN (°F)	LUBRICANT FLOW RATE (GPM)	LUBRICANT SCAVENGE RATE (GPM)	HOT AIR MANIFOLD PRESSURE (PSI)	HOT AIR TOTAL FLOW RATE (SCFM)	HOT AIR MANIFOLD TEMP. (°F)	COMPOSIT TEMP (°F)	VENT INLET NO FIRE (°F)	VENT INLET FIRE (°F)	REMARKS
1	60	0.0	No	7000	460	340	1	15	40	35	1010	1810			#1 IGNITOR
2	60	0.0	No	7000	460	340	1	15	40	35	1010	1810			#1 IGNITOR
3	60	0.0	No	7000	520	340	1	15	50	42	1020	1850			#1 IGNITOR
4	29	0.0	Yes	7000	510	340	1	15	50	42	1020	1870	790	>1500	#2 IGNITOR
5	1	0.0	Yes	7000	530	340	1	15	50	42	1010	1880	790	>1500	
6	1	0.0	Yes	7000	540	340	1	15	50	42	1010	1890	790	>1500	
7	2	2.64	Yes	7000	560	300	1	15	50	48	1000	1860	820	1280	
8	2	2.64	Yes	7000	560	280	1	15	50	48	1000	1840	830	1260	
9	2	2.54	Yes	7000	520	290	1	15	50	48	1000	1810	840	1140	
10	60	0.0	No	5300	520	350	1	15	50	47	990	1860			
11	6	0.0	Yes	5300	540	350	1	15	40	43	1000	1890	830	930	NOT SELF-SUSTAINING
12	60	0.0	No	6000	540	350	1	15	35	37	1000	1890			
13	60	0.0	No	6000	550	350	1	15	40	41	1000	1900			
14	60	0.0	No	6000	550	350	1	15	50	49	1000	1900			
15	60	0.0	No	6000	550	350	1	15	50	49	1000	1900			
16	60	0.0	No	6000	550	350	1	15	50	49	1000	1900			
17	60	0.0	No	6000	560	360	1	15	40	43	980	1900			
18	1	0.0	Yes	7000	560	360	1	15	38	45	980	1900	830	>1500	
19	1	0.0	Yes	7000	510	360	1	15	37	45	990	1860	790	>1500	
20	1	8.8	Yes	7000	480	340	1	15	37	45	990	1810	790	>1500	
21	1	8.8	Yes	7000	510	310	1	15	37	45	980	1800	800	>1500	
22	1	0.0	Yes	7000	470	380	1	15	30	38	980	1830	770	>1500	
23	1	0.0	Yes	7000	480	370	1	15	20	27	980	1830	770	980	
24	1	0.0	Yes	7000	510	370	1	15	20	27	980	1860	780	1050	
25	1	8.8	Yes	7000	500	350	1	15	20	27	980	1830	780	>1500	
26	1	8.8	Yes	7000	500	340	1	15	20	27	980	1820	780	>1500	
27	1	0.0	Yes	7000	480	380	1	15	20	28	970	1830	770	1120	
28	1	0.0	Yes	7000	480	380	1	15	20	28	970	1830	770	1170	
29	2	10.6	Yes	7000	470	340	1	15	20	28	970	1780	750	890	
30	60	10.6	No	7000	470	300	1	15	20	28	970	1740			
31	1	10.6	Yes	7000	460	340	1	15	20	27	970	1770	750	970	NOT SELF-SUSTAINING
32	3	10.6	Yes	7000	460	340	1	15	20	27	970	1770	750	970	NOT SELF-SUSTAINING

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Reviewing the composite temperature conditions in the bearing chamber, it was again observed that the more severe the conditions the more severe the fires. In tests run 30, see Enclosure 14, where no fires could be ignited, the composite temperature was 1740° F. At a composite temperature of only 30° F higher, test runs 31 and 32, fires were ignited but were not self-sustaining. In the baseline test with Mobil Jet II, see Enclosure 12, a fire was ignited with a composite temperature of 1710° F and is, therefore, considered to be the minimum condition under which fires can be ignited in the test rig when using Mobil Jet II lubricant. This value is compared to 1650° F for Esso 4040.

Freon FE1301 when mixed with the lubricant in sufficient quantities does perform as a retardant. However, the retarding mechanism appears to be the effect of cooling and not chemical in nature. Therefore, a liquid Freon with low toxic properties should prove more effective since the heat of vaporization will increase lubricant cooling.

The baffle plate between the seal and bearing again prevented bearing seizure when hot air temperatures in excess of 1500° F existed only slightly upstream.

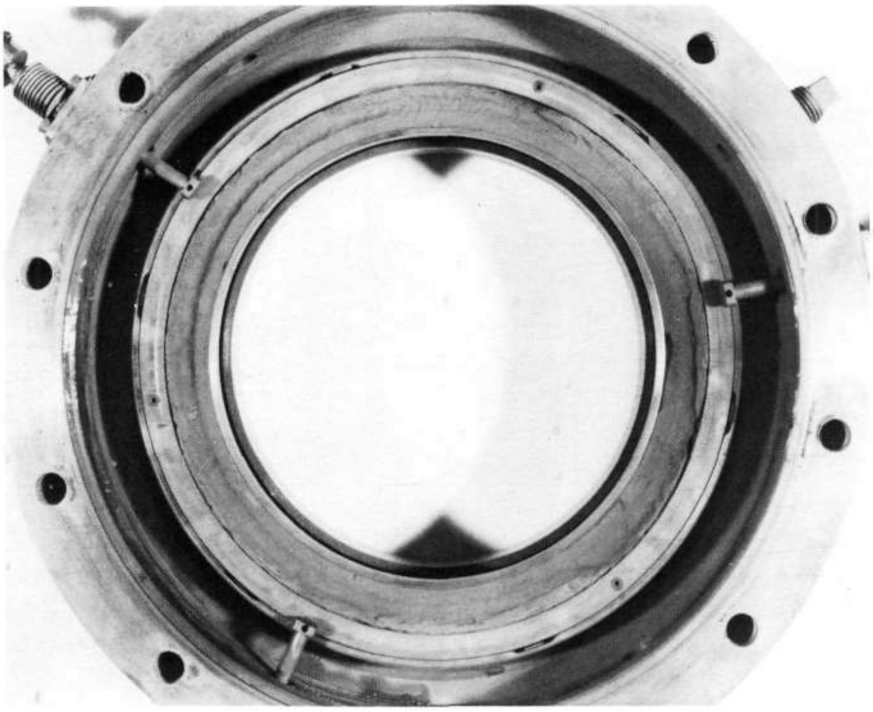
A disassembly and inspection of the rig showed that the carbon in the secondary bellows seal (seal type 700513, serial No. 1) had completely disintegrated and erosion had occurred; the seal shoulder face was badly scored, see Enclosure 15. General conditions of the other rig components were similar to those observed after the testing with Esso 4040 with more coking which could be the result of a greater number of fires. The rig interior showed signs of fire with heavy coking on the oil seal housing and the baffle plate.

D. Monsanto MCS 2931 Baseline And Fire Retardant Test

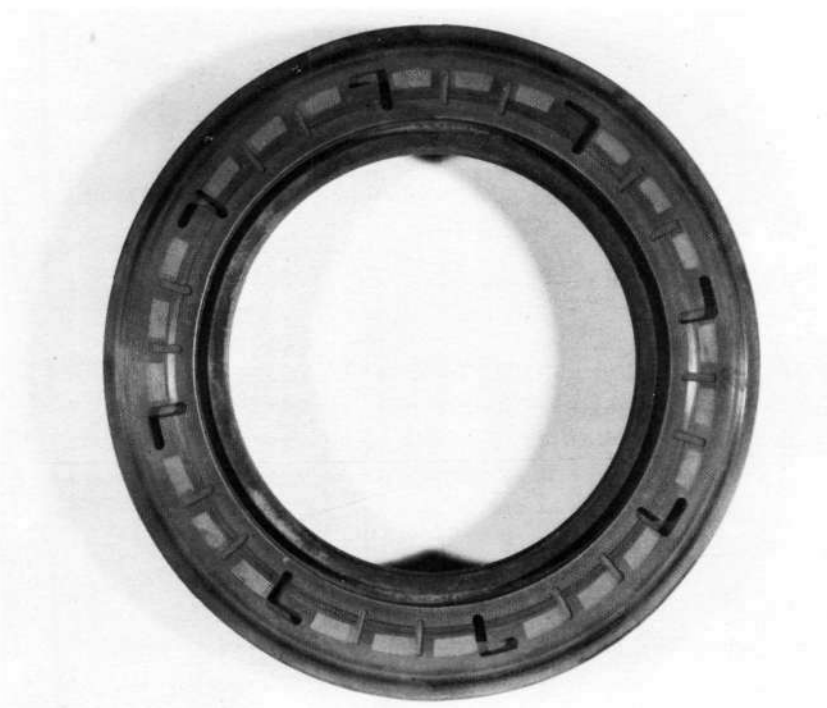
In preparation for the Monsanto MCS 2931 testing the test bearing lubrication system and rig components were cleaned and the seal replaced. The seal removed (a hybrid seal consisting of a bellows secondary with a hydrodynamic lift design shoulder type 700513, Serial No. 1) utilized a Union Carbide Company carbon material CDJ83 which, according to Stein Seal Company, has been used successfully to 1000°F

ENCLOSURE 15

SEAL CONDITION AFTER MOBIL JET II TESTS



Carbon Nose Piece In Housing



Seal Mating Ring

temperature. The replacement seal had a bellows secondary with a flat shoulder, type 700496 (Serial No. 1), using a Pure Carbon Company carbon material 56HT. According to Koppers Seal Co. this material is designed to withstand higher temperatures than the CDJ83.

The test was performed in the same manner as prior tests with the exceptions that the seal was manually held open to permit hot air flow through the bearing cavity and the hot air chamber exhaust valve was closed. Therefore, all air entering the rig passed through the bearing chamber permitting direct measurement of the bearing chamber air flow rate. Test condiions similar to those under which fires were ignited with Esso 4040 and Mobil Jet II lubricants were imposed. As with the previously tested lubricants, fires could be readily ignited using the spark generator. It was noted that a minimum composite bearing chamber temperature of 1770° F was required before a fire could be ignited, see Enclosure 16.

A total of 43 test runs were made, 14 of which utilized fire retardant Freon FE1301 in quantities varying from 2.54 to 10 percent by volume of the lubricant. A lubricant flow rate of 1 gpm was used throughout the test.

Three baseline test runs were initially performed with relatively low air flow rates of 32, 30 and 24 scfm. Fires could not be ignited with either spark ignitor. By increasing the flow rate to 39 scfm and above fires were readily ignited, thus indicating that the previous mixtures were too rich to support combustion.

A total of 9 fires were ignited prior to inserting the retardant into the test lubricant to insure the repeatability of fire ignition under the test conditions. It was observed during these tests that fires did not propagate rapidly as indicated by the exhausting hot air temperature. However, as noted in prior tests the higher the composite temperature in the bearing chamber the more rapid the propagation.

ENCLSOSURE 16

MONSANTO MCS 2931 BASELINE AND FIRE RETARDANT TEST DATA

Run No.	Spark Time (SEC)	Freon (%)	Fire	Speed (RPM)	Brg. Temp. (°F)	Lubricant: Temp. In (°F)	Lubricant: Flow Rate (GPM)	Lubricant: Scavenge Rate (GPM)	Hot Air: Manifold Pressure (PSI)	Hot Air: Brg. Cavity Flow Rate (SCFM)	Hot Air: Hot Air Manifold Temp. (°F)	Composit Temp (°F)	Vent Inlet No Fire (°F)	Vent Inlet Fire (°F)	Remarks
1	60	0.0	No	7000	460	350	1	15	30	32	1000	1810	770	-	#1 Ignitor
2	60	0.0	No	7000	460	350	1	15	30	30	1000	1810	770	-	#2 Ignitor
3	60	0.0	No	7000	460	350	1	15	20	24	990	1800	770	-	
4	1	0.0	Yes	7000	470	355	1	15	40	40	1010	1835	770	1360	
5	1	0.0	Yes	7000	500	330	1	15	40	39	1020	1850	775	1260	
6	1	0.0	Yes	5800	490	330	1	15	50	47	1020	1840	810	1280	
7	16	0.0	Yes	5800	490	330	1	15	50	47	1020	1840	810	1080	
8	11	0.0	Yes	7000	500	360	1	15	50	44	1020	1880	800	1300	
9	1	0.0	Yes	7000	500	360	1	15	50	44	1020	1880	790	>1500	#1 Ignitor
10	1	0.0	Yes	7000	500	360	1	15	50	44	1020	1880	790	>1500	
11	20	3.03	Yes	7000	480	270	1	15	50	46	1020	1770	820	1100	
12	1	0.0	Yes	7000	500	350	1	15	50	46	1020	1870	770	>1500	
13	16	2.54	Yes	7000	510	300	1	15	50	46	1020	1830	770	1020	Not Self-Sustaining
14	60	2.54	No	7000	510	260	1	15	50	46	1020	1790	770	-	
15	1	0.0	Yes	7000	500	350	1	15	50	46	1020	1870	760	>1500	
16	27	3.35	Yes	7000	500	300	1	15	50	46	1020	1820	760	840	Not Self-Sustaining
17	22	3.35	Yes	7000	500	260	1	15	50	46	1020	1780	760	880	Not Self-Sustaining
18	1	0.0	Yes	7000	500	350	1	15	50	46	1020	1870	780	1420	
19	7	7.8	Yes	7000	500	340	1	15	50	46	1020	1860	780	1330	
20	1	7.8	Yes	7000	470	300	1	15	50	46	1020	1780	780	1210	
21	5	7.8	Yes	7000	470	290	1	15	50	46	1020	1780	780	1115	
22	1	0.0	Yes	7000	490	360	1	15	50	46	1020	1780	800	1450	
23	1	10.0	Yes	7000	500	370	1	15	50	46	1020	1880	790	1310	
24	1	10.0	Yes	7000	500	300	1	15	50	46	1020	1820	790	>1500	
25	3	10.0	Yes	7000	500	300	1	15	50	46	1020	1820	790	1450	
26	8	0.0	Yes	7000	480	350	1	15	50	43	1020	1850	830	1190	
27	4	0.0	Yes	7000	480	350	1	15	50	43	1020	1850	830	1410	
28	22	2.53	Yes	7000	500	330	1	15	50	45	1020	1850	820	900	Very Slow Propagation
29	10	2.58	Yes	7000	500	260	1	15	50	45	1020	1780	820	940	Very Slow Propagation
30	20	2.58	Yes	7000	500	250	1	15	50	45	1020	1780	820	960	Very Slow Propagation
31	1	0.0	Yes	7000	490	350	1	15	50	45	1020	1860	800	1470	
32	1	0.0	Yes	7000	490	350	1	15	50	45	1020	1860	800	1440	
33	2	0.0	Yes	7000	460	310	1	15	50	43	1010	1780	800	1370	
34	60	0.0	No	7000	470	275	1	15	50	41	1010	1755	810	-	
35	60	0.0	No	7000	450	260	1	15	50	41	1010	1730	810	-	
36	60	0.0	No	7000	460	260	1	15	50	41	1010	1730	810	-	
37	60	0.0	No	7000	470	290	1	15	50	43	1010	1770	810	-	
38	60	0.0	No	7000	460	310	1	15	50	43	1010	1800	800	-	
39	1	0.0	Yes	7000	490	330	1	15	50	43	1010	1830	800	1310	
40	1	0.0	Yes	7000	490	330	1	15	50	43	1010	1830	800	1290	
41	60	0.0	No	7000	480	280	1	15	50	43	1010	1770	830	-	
42	60	0.0	No	7000	480	280	1	15	50	43	1010	1770	830	-	
43	60	0.0	No	7000	480	280	1	15	50	43	1010	1770	830	-	

Just prior and following each fire retardant test run a check was performed to insure fires could be ignited in the absence of the retardant. In all retardant test runs except one, (run #14), fires could be ignited. During this run it was observed that the oil inlet temperature had decreased to 260° F and the composite bearing chamber temperature was 1790° F.

Based on the hypothesis that the inability to ignite a fire was the result of the low oil inlet temperature and not a chemical retardation two sets of test runs were performed in the absence of Freon with the oil inlet temperature decreased gradually from 350° F to 260° F. The results of these runs showed that no fires could be ignited when the oil inlet temperature was below 280° F or when the bearing chamber composite temperature dropped to 1770° F, see Enclosure 16. This is compared to composite temperature values of 1650° F and 1710° F for Esso 4040 and Mobil Jet II respectively.

As in prior testing nitrogen purging was completely effective in extinguishing all fires.

A disassembly and inspection of the rig showed general conditions to be similar to those observed after prior tests and the seal and bearing were in good condition. Photographs documenting the seal carbon condition and heavy coking on baffle plate are presented in Enclosure 17.

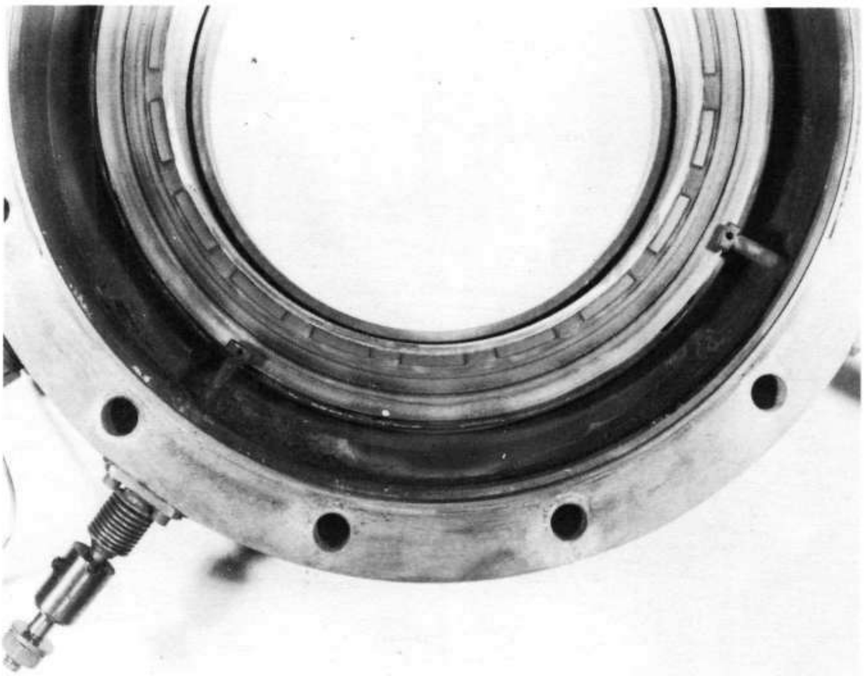
E. Rub (Friction) Ignitor Test

The rub ignitor was assembled into the rig in preparation for performing fire ignition tests with Esso 4040 lubricant.

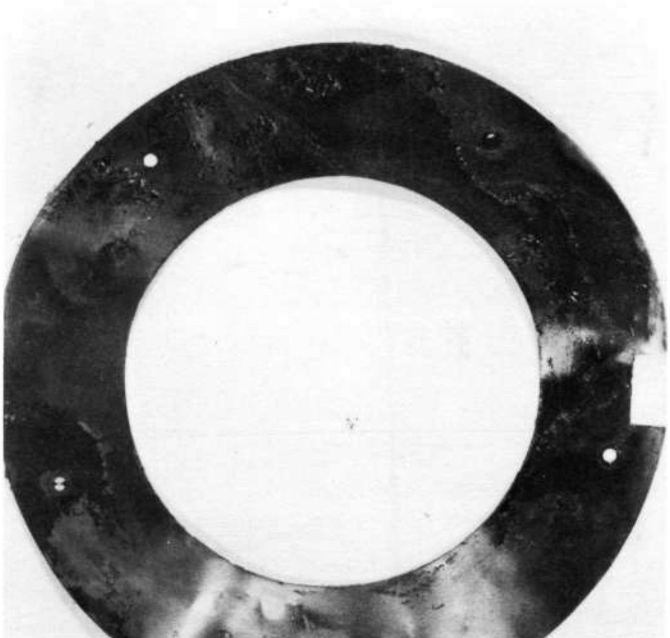
The spark ignitors were retained in the rig to permit testing to insure conditions existed which would support fires before initiating the rub ignitor tests. During a functional test of the spark ignitor prior to reaching test conditions and with the shaft stationary a fire was ignited. This was unexpected since the composite temperature in the bearing cavity was only 1490° F and no fires had been ignited with shaft speed below 5000 rpm in prior testing, see Enclosure 18.

ENCLOSURE 17

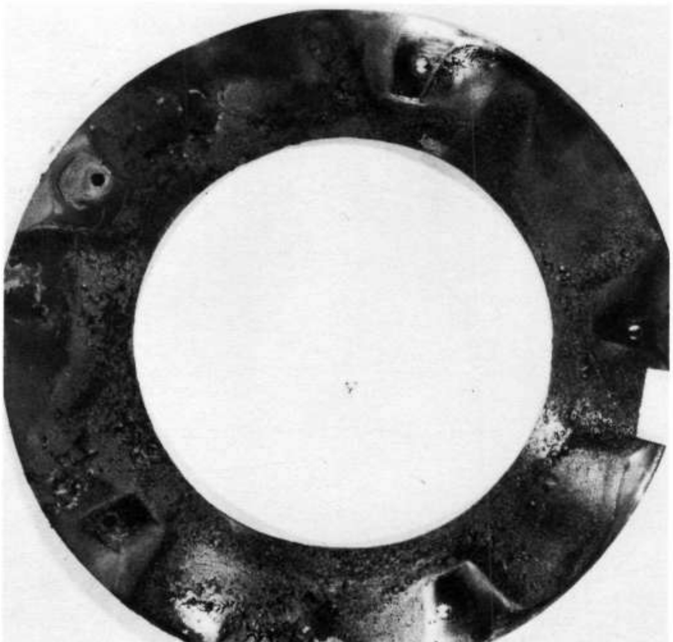
SEAL AND BAFFLE PLATE CONDITION AFTER MONSANTO MCS 2931 TEST



Carbon Nose Piece in Housing



Hot Air Side



Bearing Side

ENCLOSURE 18

ESSO 4040 RUB IGNITOR TEST DATA

Run (No)	Fire	Spark Time (Sec)	Shaft Speed (RPM)	Brg. Temp (°F)	Lubricant Temp In (°F)	Lubricant Flow Rate (GPM)	Lubricant Scavenge Rate (GPM)	Hot Air Manifold Pressure (PSI)	Hot Air Brg. Cavity Flow Rate (SCFM)	Hot Air Manifold Temp. (°F)	Composit Temp. (°F)	Exhaust Air Vent Inlet Prior To Ignition (°F)	Exhaust Air Vent Inlet After Ignition (°F)	Rub Ignitor Temp. Before /After (°F)	Remakrs
0	YES	5	0	350	240	1	15	14	23	900	1490	700	1500		Preliminary Check of Spark Ignitor (#2 Spark Ignitor)
1	NO	60	7000	460	300	1	15	20	26	940	1700	750	-		#1 Spark Ignitor
2	NO	60	7000	460	300	1	15	20	26	940	1700	750	-		#1 Spark Ignitor
3	YES	40	0	460	320	1	15	20	28	940	1720	750	930		#1 Spark Ignitor
4	YES	3	0	460	320	1	15	20	28	940	1720	750	850		#2 Ignitor
5	NO	60	6000	420	340	1	15	20	26	940	1700	770	-		#2 Ignitor
6	NO	60	5100	420	340	1	15	20	26	940	1700	770	-		#2 Ignitor
7	No	60	0	550	330	1	15	20	29	1000	1880	840	-		#2 Ignitor
8	No	60	0	550	330	1	15	10	20	1000	1880	830	-		#2 Ignitor
9	Yes	35	0	550	330	1	15	10	20	1000	1880	810	860		#1 Ignitor
10	No	60	5700	450	340	1	15	40	39	1020	1810	830			
11	Yes	15	5500	450	340	1	15	40	39	1020	1810	830	>1500	409	Rub Ignitor-5 Sec before fire. Max. Force - 300 lbs.
12	YES	15	5500	550	350	1	15	40	39	1020	1920	820	1400	756/1800	Rub Ignitor-3 Sec before fire. Max. Force - 70 lbs.
13	Yes	15	5500	520	380	1	15	40	39	1020	1920	820	>1500	756/2250	Rub Ignitor-2 Sec before fire. Max. Force - 200 lbs.

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This occurrence indicated, as did the results of previous tests with Esso 4040, that fires would be easily ignited when test conditions were reached. However, this did not prove to be true when the shaft was rotated. Five test runs with shaft speed varying from 5100 rpm to 7000 rpm with oil inlet and hot air inlet temperatures from 300 to 340°F and 940 to 1020°F respectively produced only one minor fire. Test data is presented in Enclosure 18. Five additional tests with the shaft stationary resulted in three additional minor fires giving additional evidence of the effect of shaft speed on the oil-air mixture within the bearing cavity.

The difficulty of producing fires with the spark ignitor can only be attributed to changes made in the bearing chamber to accommodate the rub ignitor. These include the increase of radial clearance between the baffle plate and shaft by 0.25 inches and an additional hole (1.25 x 0.75 inches) in the outer edge. These two openings permitted additional air to pass through the test bearing. It is assumed that this flow effected the oil-air ratio. No other reason could be established which may have altered fire ignition conditions in the bearing cavity; showing therefore, that even minor modifications can alter fire susceptibility.

Although fires could not be started reliably with the spark ignitor, three rub ignitor tests runs were performed. In all three, fires were ignited.

The first rub ignitor test was performed with a composite temperature of 1810° F and a shaft speed of 5500 rpm. Since the shaft speed was well below 14,000 rpm, for which the rub ignition was designed, a fairly large force of 300 lbs. was applied to insure sufficient heating. The actuating force was applied for 15 seconds. After 5 seconds a fire was sensed. Two, approximately 1 second blasts of nitrogen gas were required to extinguish the fire which appeared to be more severe than any fires started in any testing with the spark ignitor. The severity of the fire was based on the rapid increase in the hot air exhaust temperature and the quantity of smoke. The difficulty of extinguishing the fire was assumed to result from not removing the ignition source (hot spot).

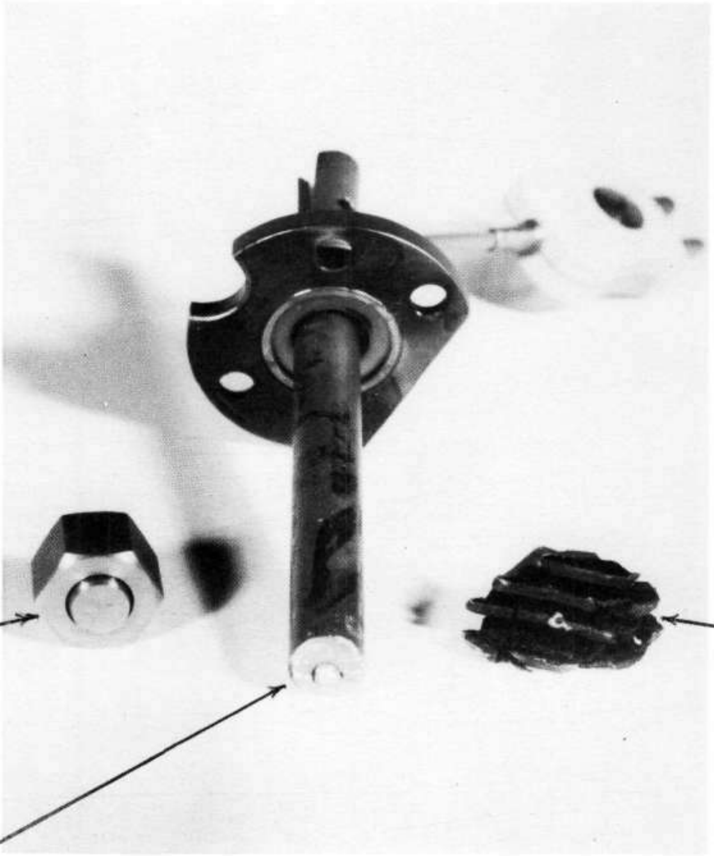
A malfunction of the thermocouple recorder prevented the evaluation of the ignitor tip temperature during actuation. Prior to the actuation the tip temperature was 360° F. Five minutes after the test the tip temperature was 800° F and remained at that temperature until the second rub ignitor test was performed 26 minutes after the first test. A check of the external portion of the rub mechanism indicated that approximately 0.125 inches of the rub sample had been removed as indicated by the position of the actuator. It was assumed that a very high temperature had been reached permitting the removal of the material. Although the special 0.062 in. thick braze material was probably removed during the first test, a second and third test were performed.

During the second test a force of only 70 lbs. was applied to the actuator. Within three seconds a fire was ignited and the air temperature exhausting from the bearing chamber increased to 1400° F before nitrogen was applied to extinguish the fire. The ignitor tip thermocouple indicated a maximum temperature of 1800° F. Since the fire did not appear as severe as in the previous test, a force of 200 lbs. was applied during the third test. A fire was ignited and the air temperature increased rapidly to a value above 1500° F. The ignitor temperature increased to a value of greater than 2250° F, which is the maximum capability of the recording instrument, when the thermocouple failed.

After the completion of the test it was observed that the bellows sealing the ignitor access hole had completely flattened and the rod extended approximately 0.5 inches below its original position. Disassembly of the rig revealed that the Inconel sleeve had moved axially forward approximately a 0.35 inches and only a portion of the rub tip, including the nut, had made contact with the sleeve. The area making contact had been machined off allowing the remaining portion of the tips to make contact with the Inconel labyrinth seal located beneath the original location of the sleeve. The tip, including the nut and a portion of the extension rod, had conformed to the shape of the seal, see Enclosure 19.

ENCLOSURE 19

RUB IGNITOR - CONDITION OF TIP BEFORE AND AFTER TEST



Rub Tip and Nut Prior to Test

Rub Tip and Nut After Test

Extension Rod and Thermocouple

Fires could be readily started with a rub ignitor while a spark ignitor was less effective. A hot spot resulting from a friction rub will produce fires under conditions where an electrical spark will not start a fire. This should be expected since the energy dissipated in the rub ignitor was estimated to be about 100 times as great as the spark ignitor. Any additional testing should be performed with a rub ignitor.

CONCLUSIONS

The principal conclusions reached as the result of the project are:

1. The principal parameters influencing fires in bearing chambers of gas turbines, identified in this program were: chamber design; hot air inflow rate and temperature; operating speed, oil flow and temperature and bearing temperature. Lubricant type had a moderate effect. Fire retardant additives were moderately helpful. The severity of conditions needed to ignite and sustain a fire depended on the source of ignition. An external energy source: a spark or the heat from high speed sliding were needed to ignite a fire under all conditions tested but once ignited, many fires are self-sustaining.

2. In every test run in which fires were ignited, purging the test bearing chamber with nitrogen gas was effective in extinguishing the fire within seconds. This remained true even when temperatures of the exhausting gas were in excess of 1500° F. Fires started by the rub ignitor appeared to be more difficult to extinguish (required a greater quantity of nitrogen gas) than those ignited by the electrical spark. In all cases the ignition source was deactivated prior to applying the nitrogen gas.

A nitrogen purging system triggered by a thermocouple sensing bearing cavity air temperature promises to be effective in extinguishing fire quickly. Test results indicate that such a system would be completely effective if the ignition source (rubbing) was eliminated or operating conditions within the sump were rendered less severe.

3. Both liquid Freon 113 and gaseous Freon FE1301 when mixed with the test lubricant had some effect in preventing ignition of fires and their propagation. The major retarding mechanism was probably cooling. Freon in a liquid state was found more effective which may be the result of the heat of vaporization increasing the cooling capacity. However, Freon 113 is a questionable fire mitigating agent since it could produce toxic gas at the combustion temperatures.

4. A metal baffle plate located between the bearing and the hot air entrance into the bearing chamber is helpful in preventing a thermal bearing seizure resulting from hot air impinging on the bearing during a seal failure. The baffle plate prevented propagation of the fire to areas further downstream and thus localized the fire to the area between the seal and plate.

5. Fires could not be started with Esso 4040 and Monsanto MCS 2931 lubricants with a spark ignitor unless the hot air leakage rate into the bearing chamber was above 15 to 20 scfm and 30 to 35 scfm respectively. This is equivalent to approximately 36 changes of air per minute for Esso 4040 and 66 changes per minute for MSC 2931. The incorporation of any device which limits air flow into the oil sump (bearing chamber) when a primary seal fails, is likely to limit fires. It must be noted, however, that the oil-air mixture in the cavity is also a function of oil flow and distribution and no value of the oil-air ratio can be established which is valid regardless of chamber design.

6. Fire ignition is sensitive to the location of the ignition source. This indicates that the oil-air mixture is not homogeneous throughout the chamber and that both combustible and incombustible mixtures are present.

7. Although differences between the severity of test conditions required to obtain fires using a spark ignitor with the three test lubricants were not large, a ranking of the most to least difficult lubricants to ignite is in the order of Monsanto MCS 2931, Mobil Jet II, and Esso 4040. This rating is based on the minimum composite temperature of the test bearing, inlet oil, and hot air in the test bearing cavity with which a fire could be ignited and are 1770, 1710 and 1650°F respectively. Fire susceptibility is in the same area as the Spontaneous Ignition Temperature (S.I.T) of the test fluids.

8. There appeared to be no combination of the specified operating conditions that would produce spontaneous ignition in the test rig with Mobil Jet II lubricant. However, fires did result in the bearing chamber when using Esso 4040, Mobil Jet II, and Monsanto MCS 2931 lubricants at relatively severe conditions when a spark generator was used as an ignition source.

9. Fires readily ignited in the bearing chamber using Esso 4040 lubricant, the only lubricant evaluated, with a rub (friction) ignitor. Although only minimal testing was performed (three test runs) with the rub ignitor, fires started in each attempt and were in general more severe and more difficult to extinguish than those occurring when employing the spark ignitor. Test results indicated that the rub ignitor would ignite fires under conditions insufficiently severe to result in fires when the spark ignitor was employed.

10. Minor changes in shaft speed are sufficient to modify combustion conditions within the bearing chamber. Higher speed generally favors combustion since it produces greater misting of the lubricant, thus, increasing the exposed liquid surface area.

11. Spontaneous combustion did not result in the 1.5 inch bearing chamber vent line when the skin temperature was maintained at 1000°F and the oil-air mixture passing through the vent was 650°F.

12. A thermocouple located within the bearing cavity is an effective means of detecting the presence of fires and can be used to trigger a fire extinguishing system. An ultraviolet flame detector was not a satisfactory means of detecting fires since oil plating and fogging of the lens impairs performance.

APPENDIX A

FIRE EXTINGUISHING EFFECTIVENESS AND TOXICITY OF SOME FREON COMPOUNDS

"Freon-114B2" dibromotetrafluoroethane, like all other "Freon" compounds, is nonflammable and, therefore, offers no fire hazards in handling or storage. Moreover, while not commercially promoted for such uses, "Freon-114B2" possesses good fire extinguishing characteristics and data regarding its effectiveness in comparison with chemical agents which have been promoted as fire extinguishing agents are presented in Tables 4 and 5 for their possible interest.

Of the compounds listed in Table 4, incidentally, "Freon" FE 1301 is recommended as the optimum fire extinguishing agent, considering not only effectiveness in extinguishing Class B and C fires but also relatively low toxicity. Complete details regarding use of "Freon" FE 1301 as a fire extinguishing agent are presented in Technical Bulletin B-29, available from the "Freon" Products Division of the Du Pont Company.

Further tests comparing the effectiveness of the "Freon" compounds in extinguishing standard gasoline fires have been carried out by the C.A.A. Test Station at Indianapolis, Indiana. Table 5 correlates data taken from several of their reports on this subject.

TABLE 4 EFFECTIVENESS OF FIRE EXTINGUISHING AGENTS IN LABORATORY EXPLOSION-PREVENTION TESTS

Common Name	Chemical Formula	Effectiveness		Boiling Point	
		Vol. %	Wt. %	°C	°F
Carbon Tetrachloride	CCl_4	2.5	12.7	76.8	170.2
"Freon" FE 1301	$CBrF_3$	1.1	5.6	-60	-76
Bromochloromethane	CH_2BrCl	1.0	4.5	67	152.6
"Freon-114B2"	$CBrF_2$-$CBrF_2$	0.85	7.4	47.5	117.5
Methyl Bromide	CH_3Br	0.8	2.7	4.5	40.1
FE 1202	CBr_2F_2	0.5	3.7	24.5	76.1
FE 1211	$CBrClF_2$	0.5	2.9	-4	25

TABLE 5 EFFECTIVENESS OF AGENTS IN EXTINGUISHING STANDARD GASOLINE FIRES

Common Name	Chemical Formula	Pounds of Agent to Extinguish Standard Fire
Methyl bromide	CH_3Br	0.10
"Freon" FE 1301	$CBrF_3$	0.10
FE 1211	$CBrClF_2$	0.105
Bromochloromethane	CH_2BrCl	0.11
"Freon-114B2"	$CBrF_2$-$CBrF_2$	0.12
FE 1202	CBr_2F_2	0.125

Toxicity

The toxicities of "Freon-114B2" and a number of other compounds are compared in Table 6. The studies reported in columns (1) and (2) were carried out at the Army Chemical Center and are reported in the NFPA Quarterly for October 1951. Rats were exposed for 15 minutes to air containing various concentrations of the agents. In one series the undecomposed vapors were used and in another the decomposed vapors obtained when the compound was passed through an iron tube heated to 800°C. The compound was exposed to this temperature for 1 second.

TABLE 6 APPROXIMATE LETHAL CONCENTRATION OF COMPOUNDS TOWARD RATS

Agent	Formula	(1) ALC for 15-Min. Exposure, ppm	(2)	(3) Underwriters' Classification
		Not Heated	Heated to 800°C	
"Freon" FE 1301	$CBrF_3$	800,000	14,000	6
Carbon dioxide	CO_2	658,000	658,000	5
"Freon-12"	CCl_2F_2	-	-	6
"Freon-113"	$CClF\text{-}CClF_2$	-	-	4-5
"Freon-114B2"	$CBrF_2\text{-}CBrF_2$	126,000	1,600	4-5
FE 1202	CBr_2F_2	54,000	1,850	4
Carbon tetra-chloride	CCl_4	28,000	300	3

Classification by the Underwriters' Laboratories, col. (3), is based on tests with vapors of the undecomposed agents on guinea pigs. According to the Underwriters' system of classification, gases in Group 6 include those which do not appear to produce injury in concentrations up to at least 20 percent by volume for exposures of about 2 hours. Materials which are lethal in concentrations of 1/2 to 1 percent for 5-minute exposures are placed in Group 1. Other substances are rated in intermediate groups depending upon their exposure and toxic effect relative to these 2 groups. This system of classification has been used for many years to indicate the comparative life hazards of refrigerants and other chemical products.

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